



Update on NIF and NIC

Presentation to
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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

NIF is the culmination of a decades-long effort to demonstrate fusion ignition and energy gain

Janus, 1974



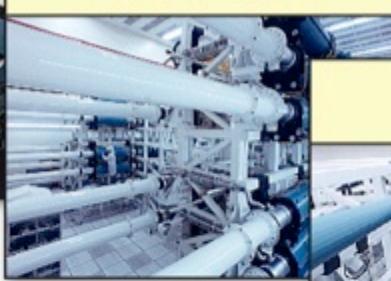
100J IR

Argus, 1976



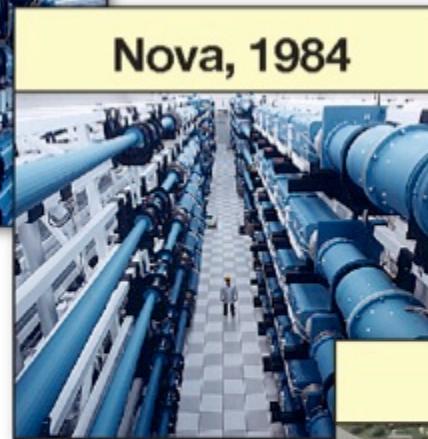
1kJ IR

Shiva, 1977



10kJ IR

Nova, 1984

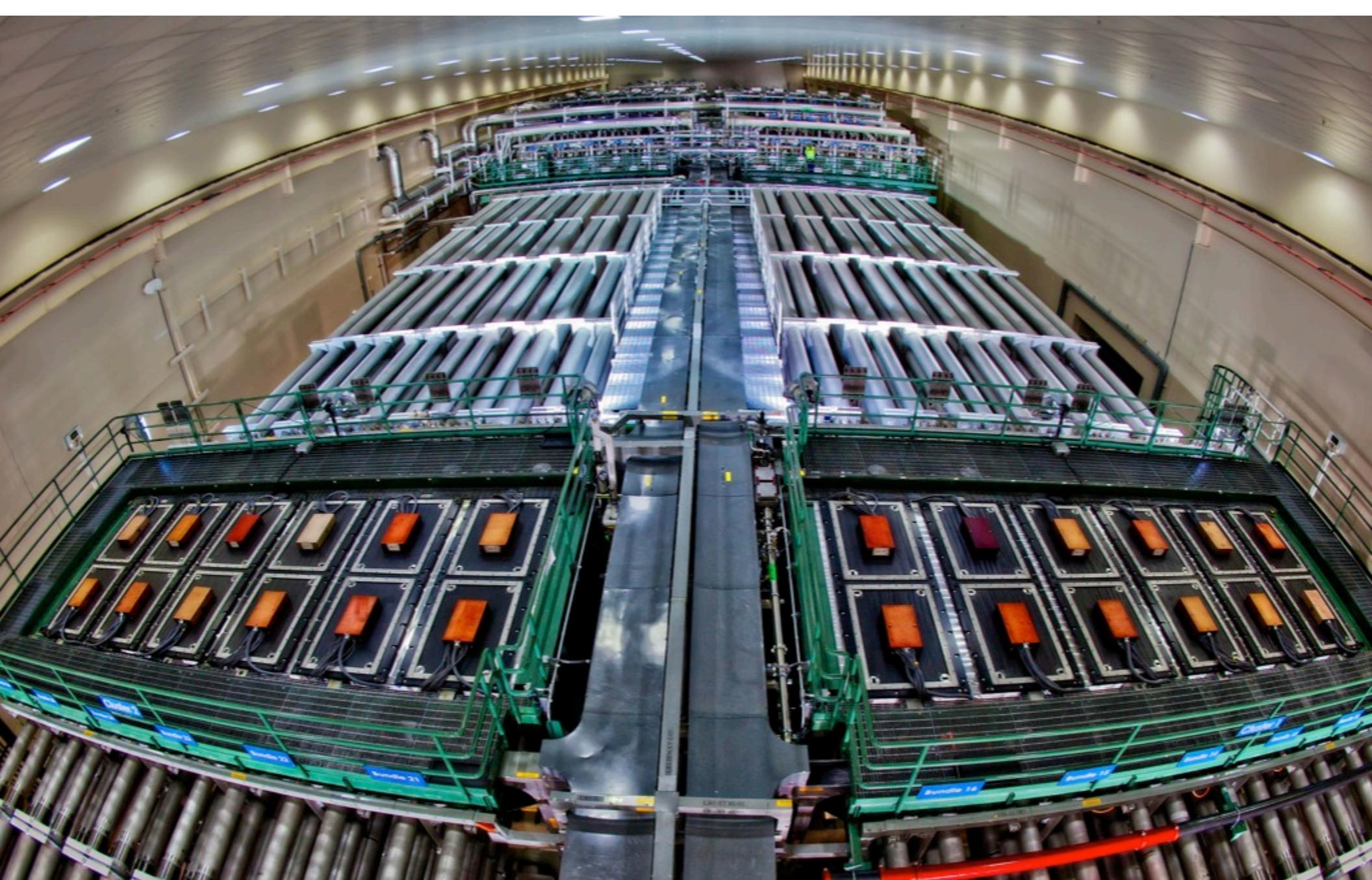


30kJ UV

NIF will demonstrate full-scale performance

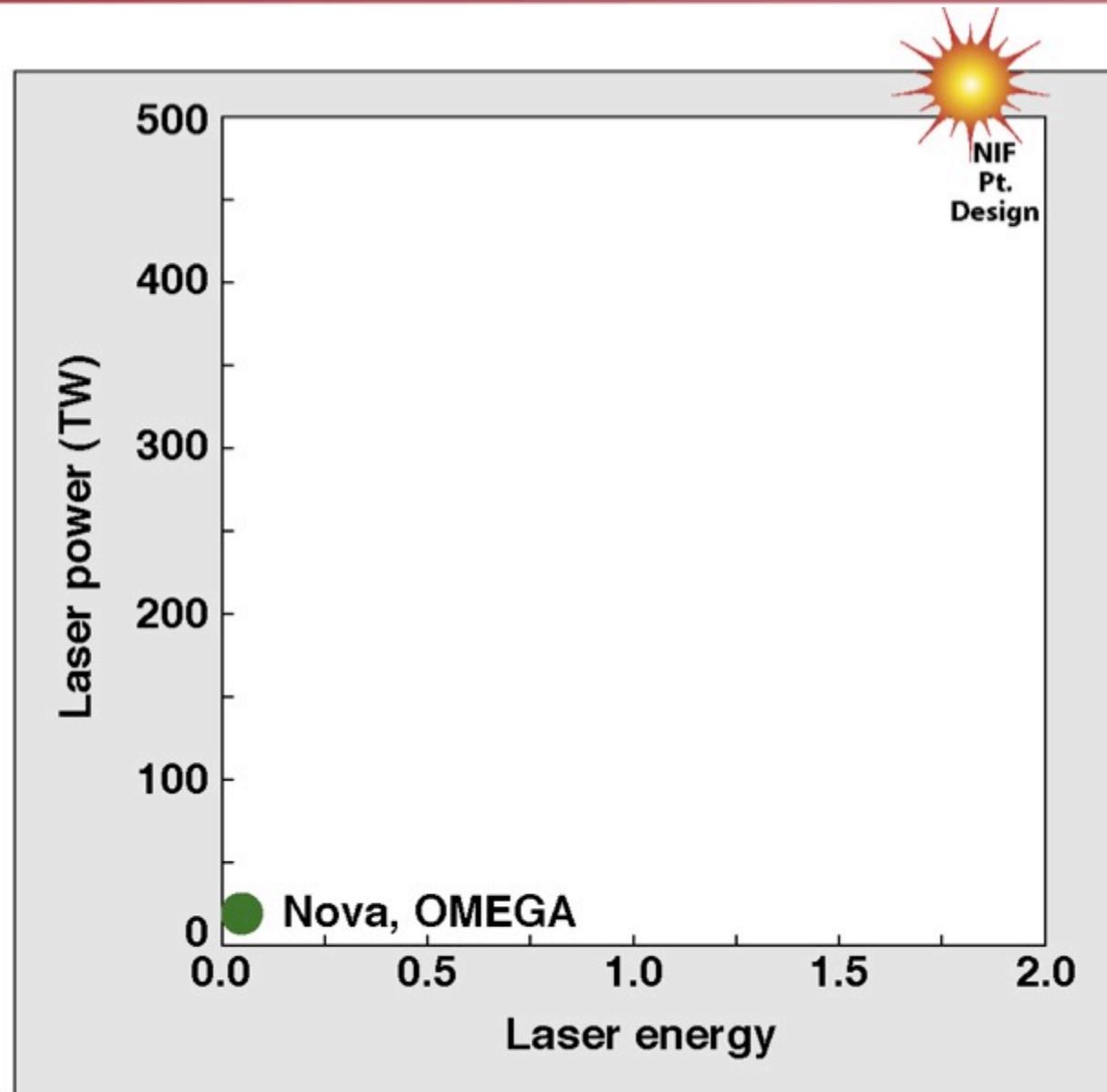


1.8 MJ UV

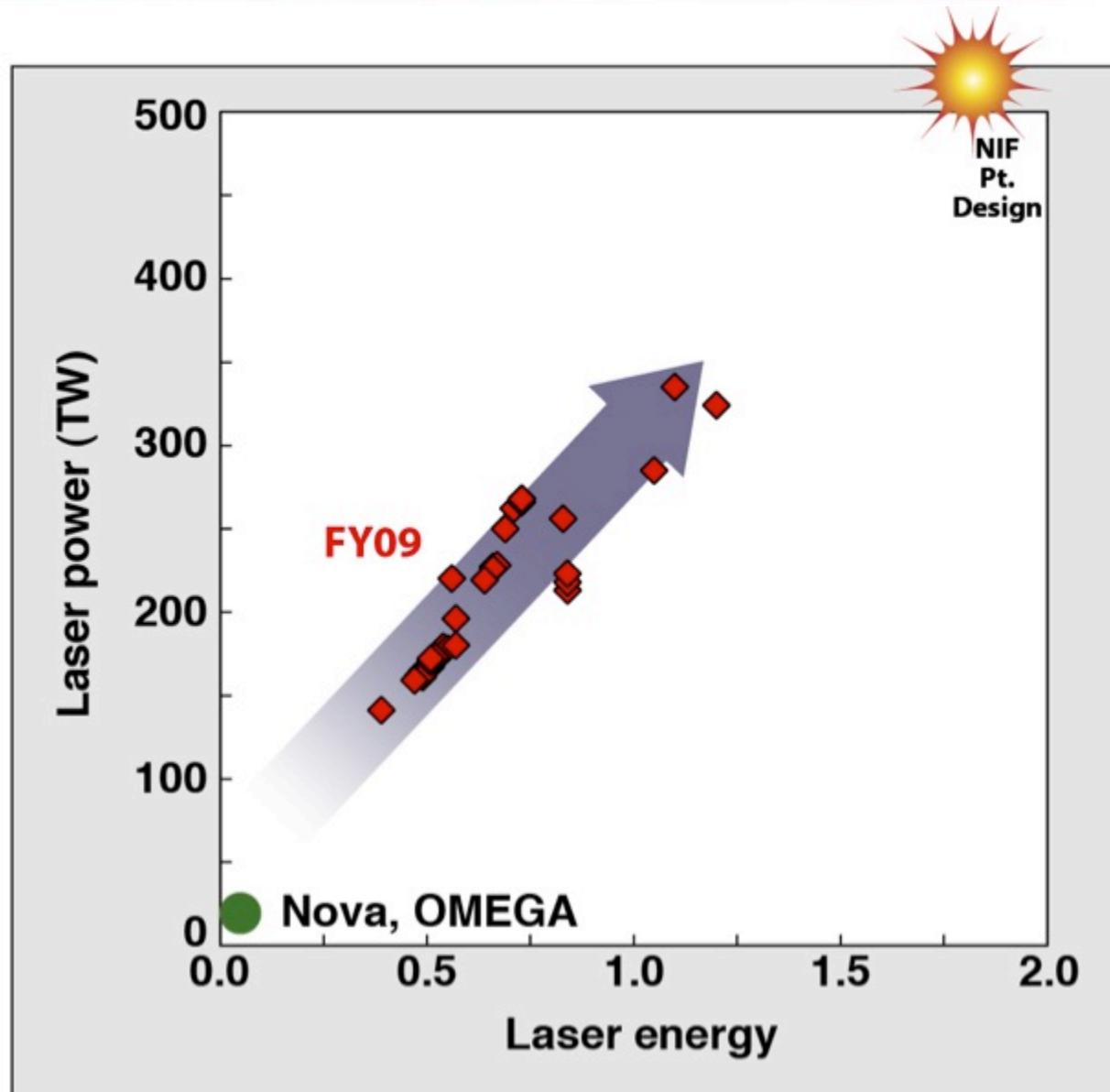


The NIF facility is running 24 hours a day – with shot reliability of over 99%

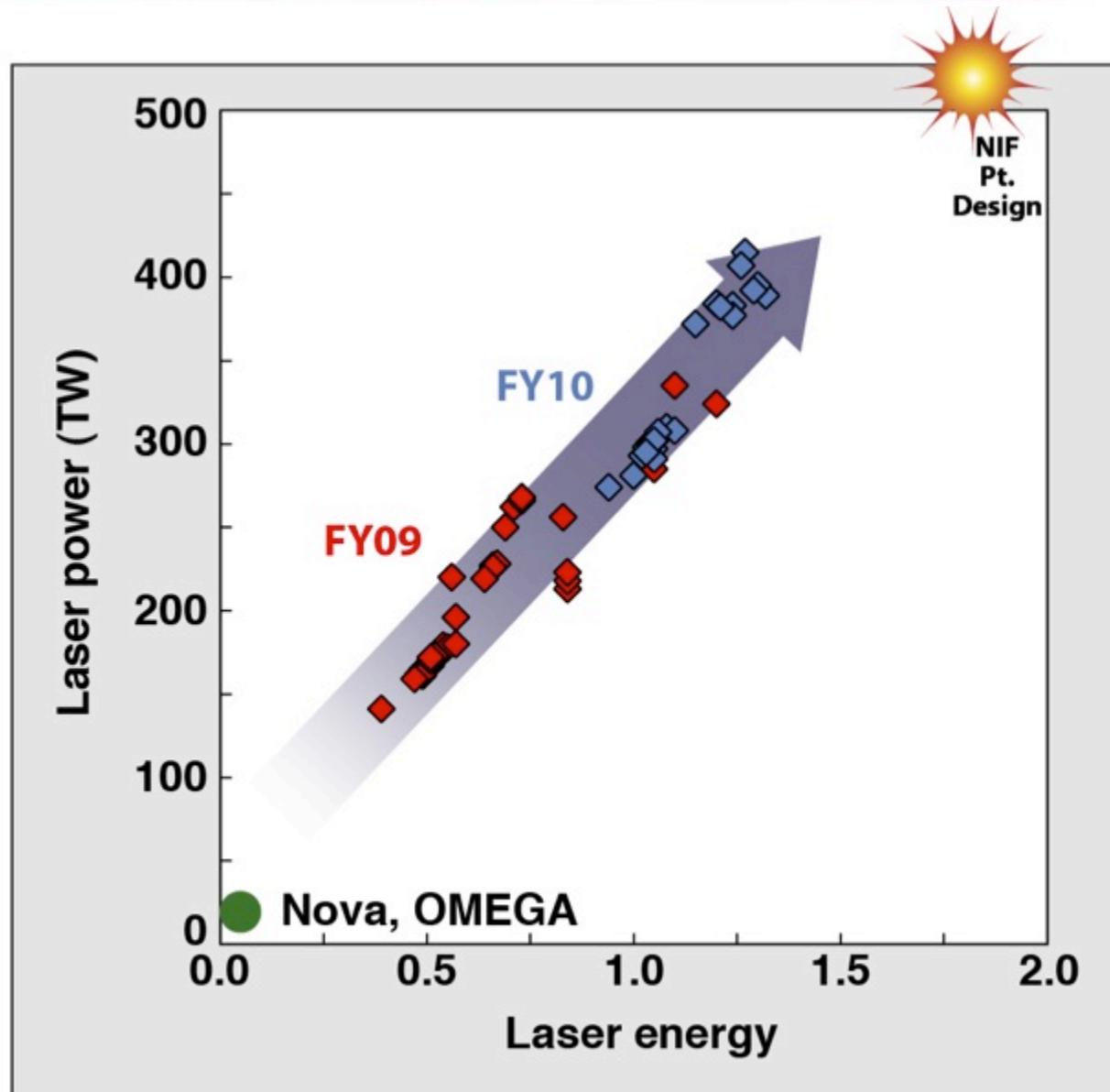
We are steadily increasing the laser energy and power available for ignition experiments



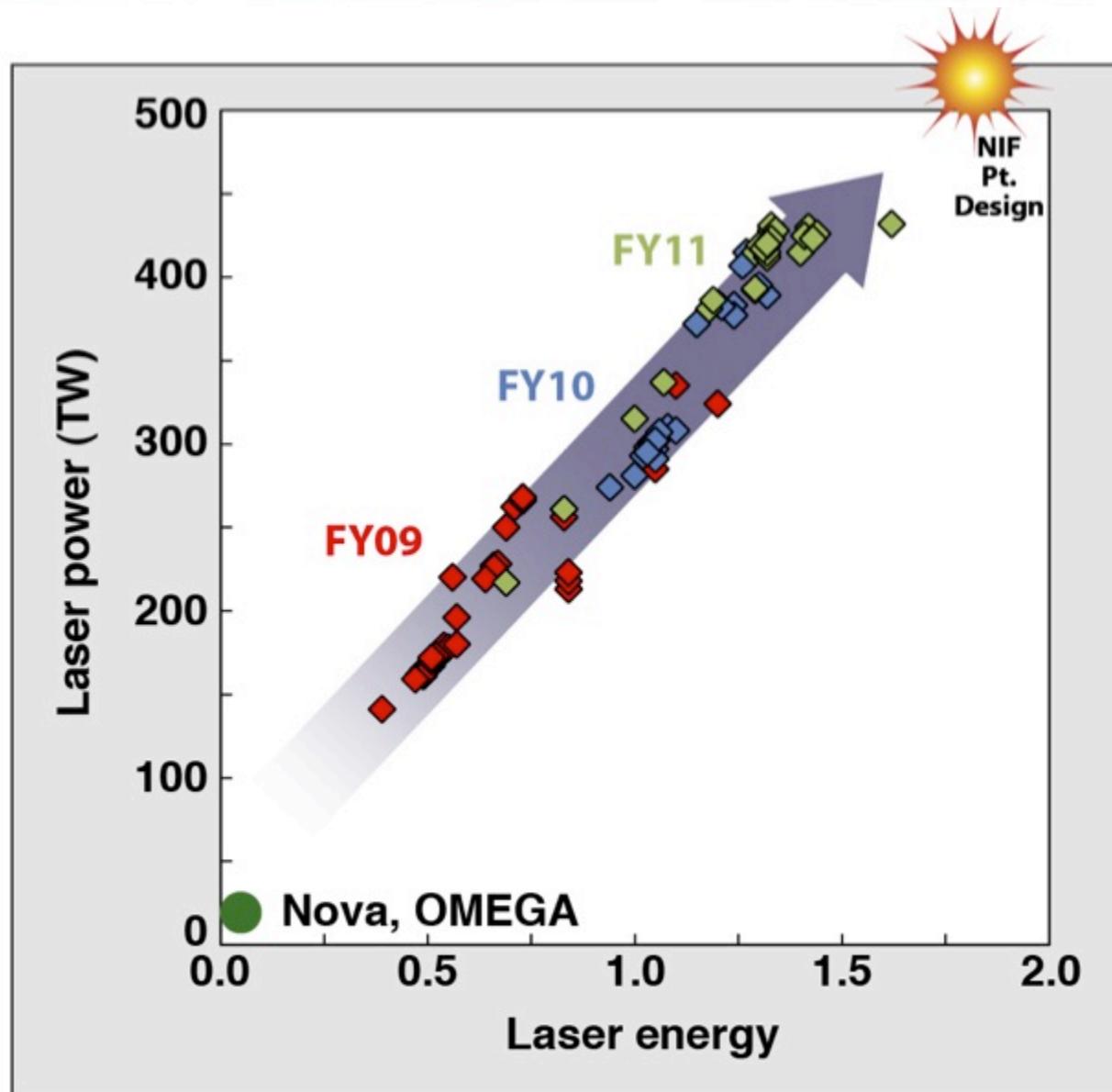
We are steadily increasing the laser energy and power available for ignition experiments **2009**



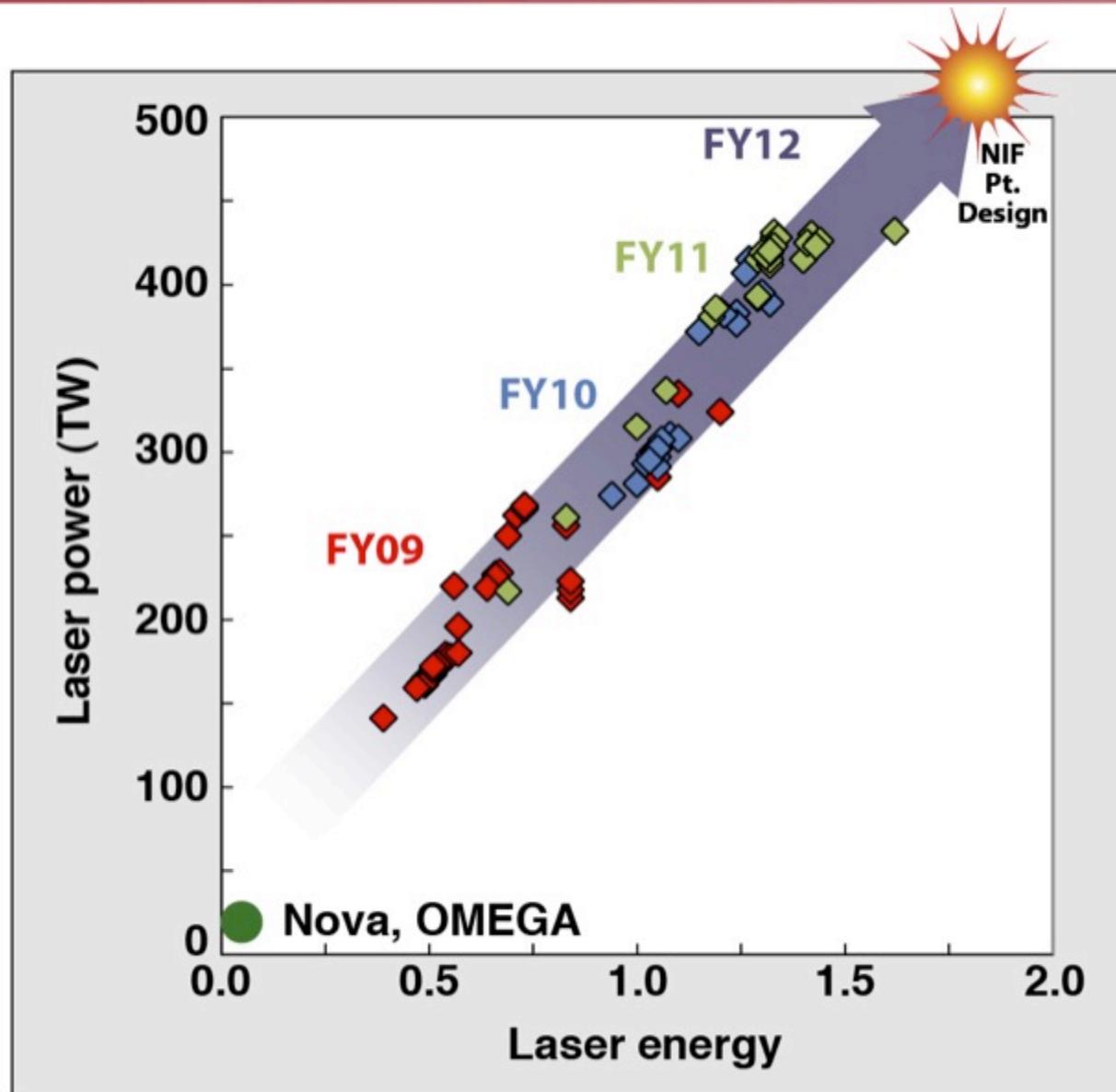
We are steadily increasing the laser energy and power available for ignition experiments 2010



We are steadily increasing the laser energy and power available for ignition experiments **2011**



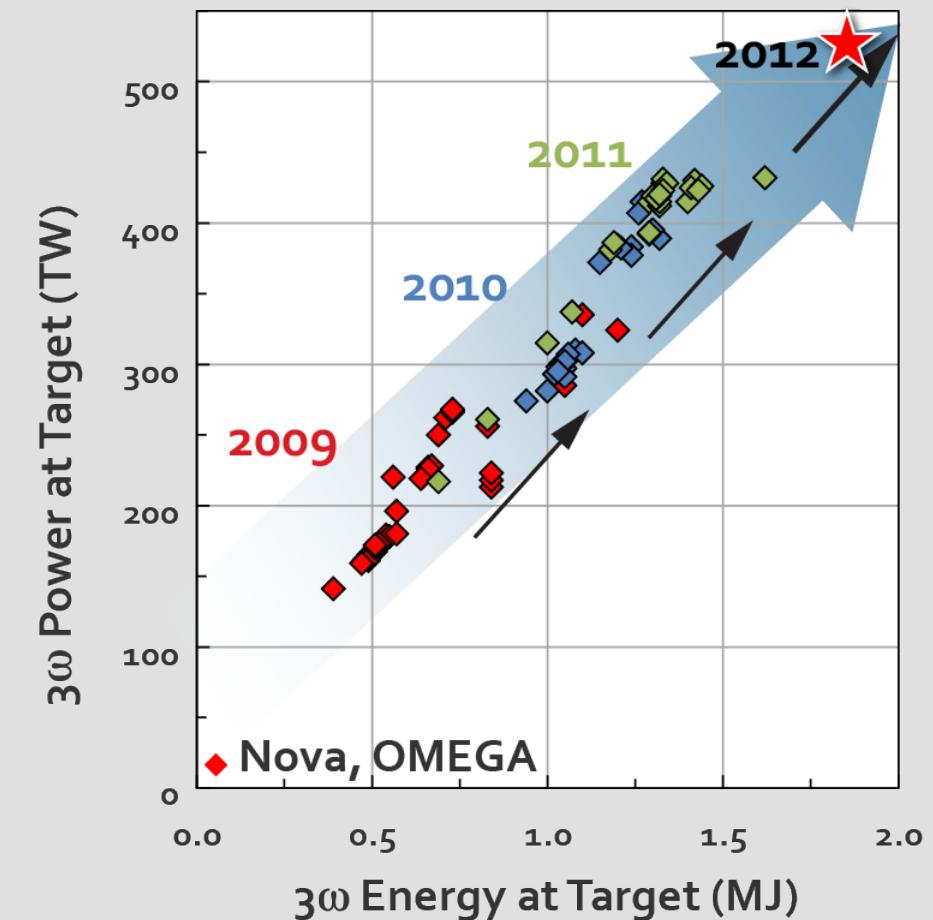
We are steadily increasing the laser energy and power available for ignition experiments 2012



NIF recently exceeded its design goal of sustainable operations at 1.8MJ / 500TW

- NIF has been steadily increasing its laser energy and power
- NIF is now operating 24/7 with exceptional reproducibility and reliability (99%)
- Currently supporting the NIC in 1.4 to 1.8 MJ campaigns
- **1.855 MJ, 522 TW achieved in a NIC-relevant pulse format**
- The NIF has intrinsic capability to continue on this growth path for several more years

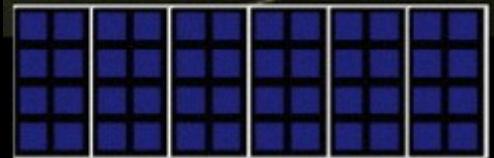
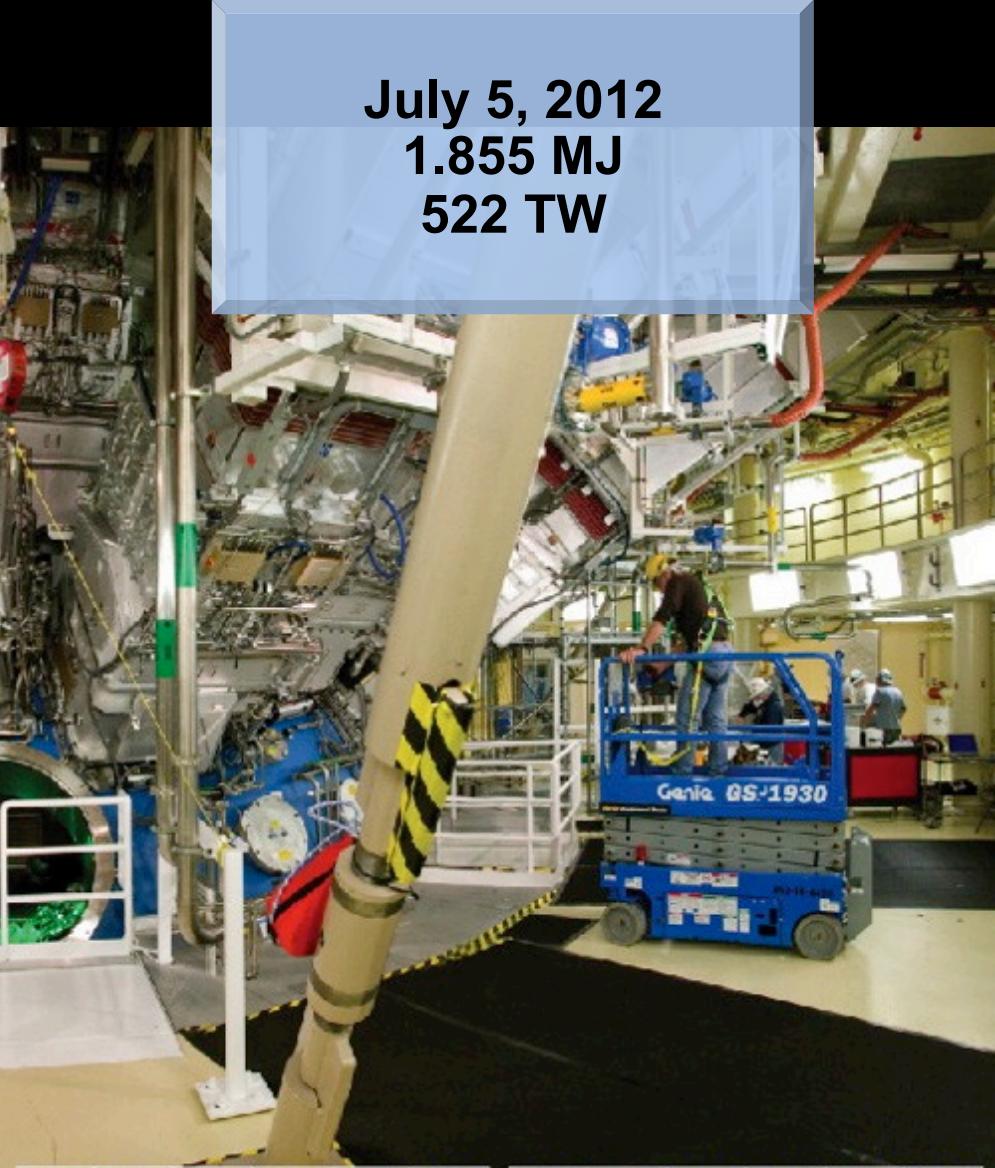
The laser energy and power available for experiments have been steadily increasing



March 15, 2012
1.875 MJ
411 TW



July 5, 2012
1.855 MJ
522 TW



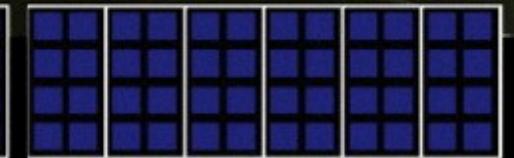
Cluster 4



Cluster 3

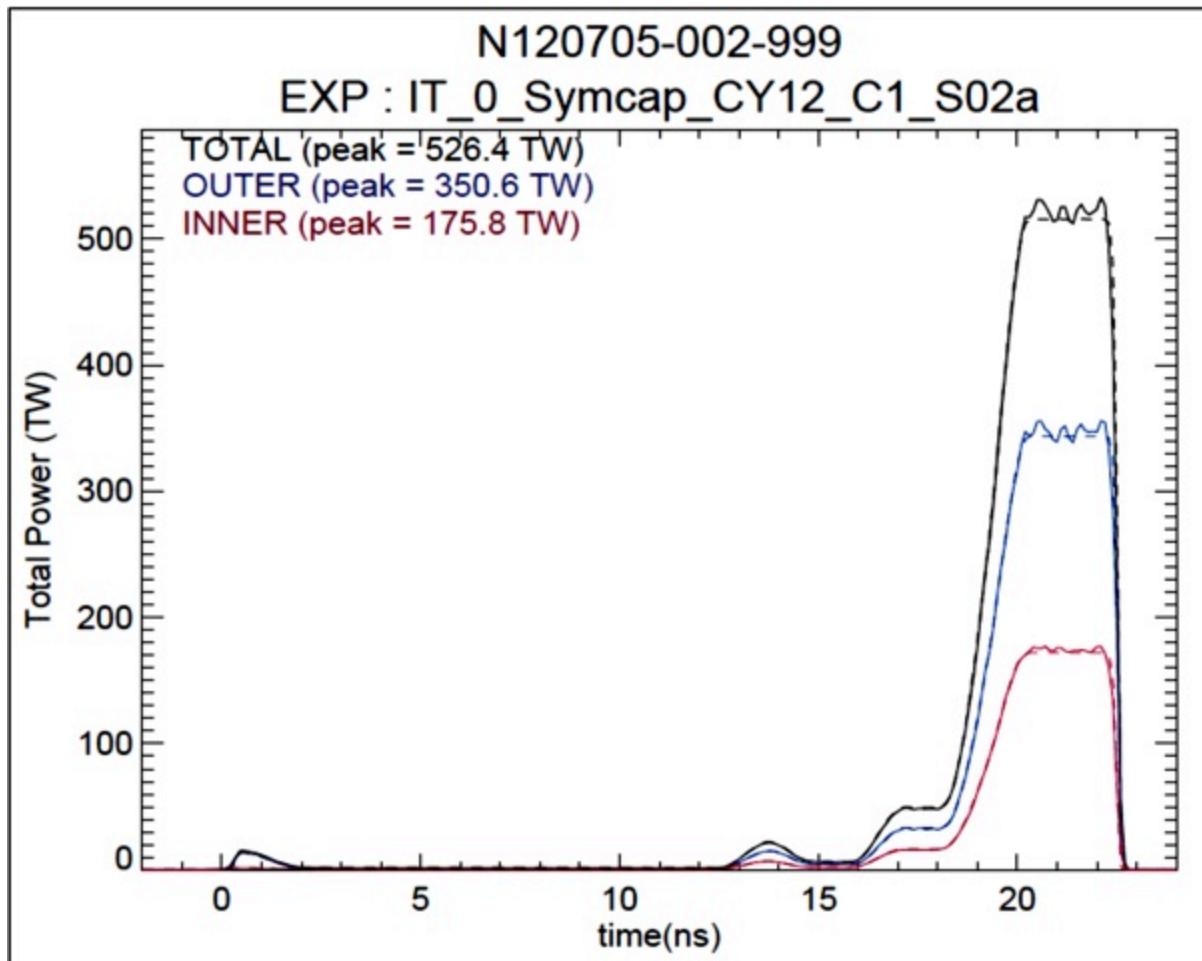


Cluster 2



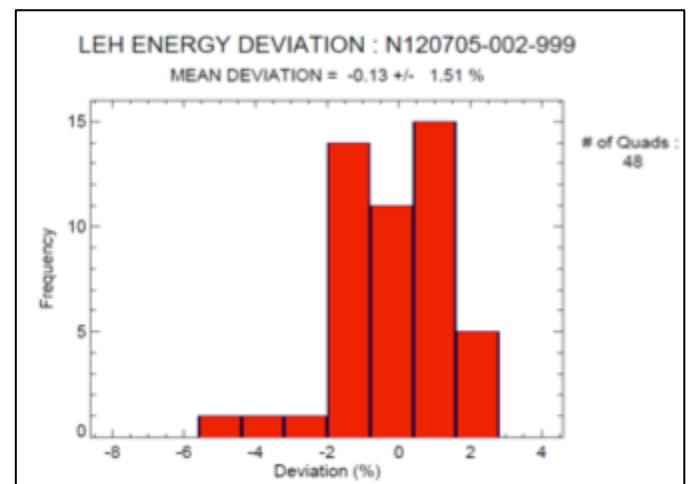
Cluster 1

Beam balance and accuracy exceeded design goals

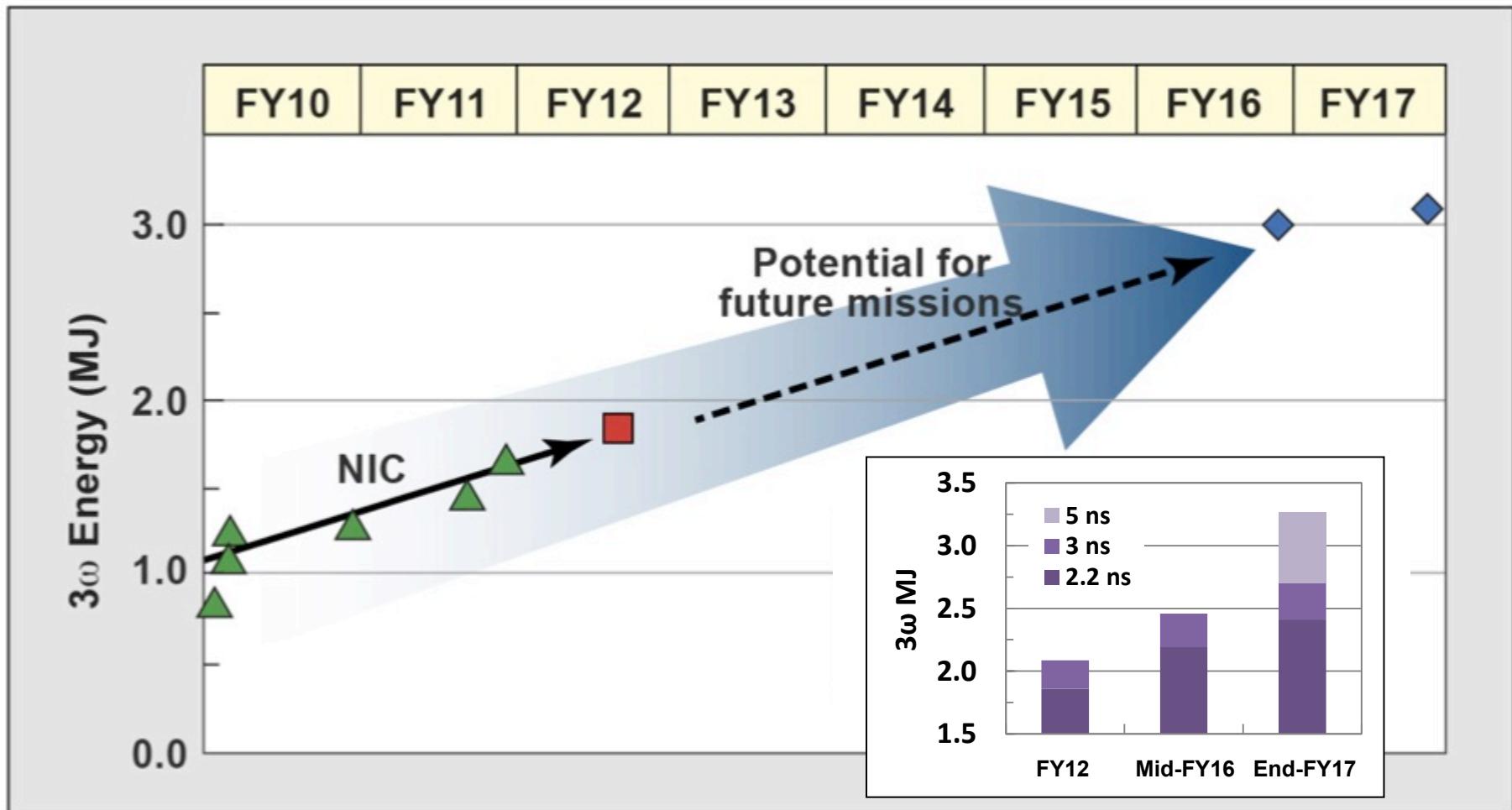


Excellent accuracy and beam balance:

- -0.13% deviation of total delivered energy
- 1.5% rms deviation of individual quad energy
- 1.6% rms quad peak power imbalance (3% goal)



Plans are being developed for enhanced NIF performance, via incremental improvements



NATIONAL IGNITION CAMPAIGN



NNSA
National Nuclear Security Administration

**GENERAL
ATOMICS**

**UR
LLE** ☼

**Lawrence Livermore
National Laboratory**

**Los Alamos
NATIONAL LABORATORY**

**Sandia
National
Laboratories**

MIT

AWE

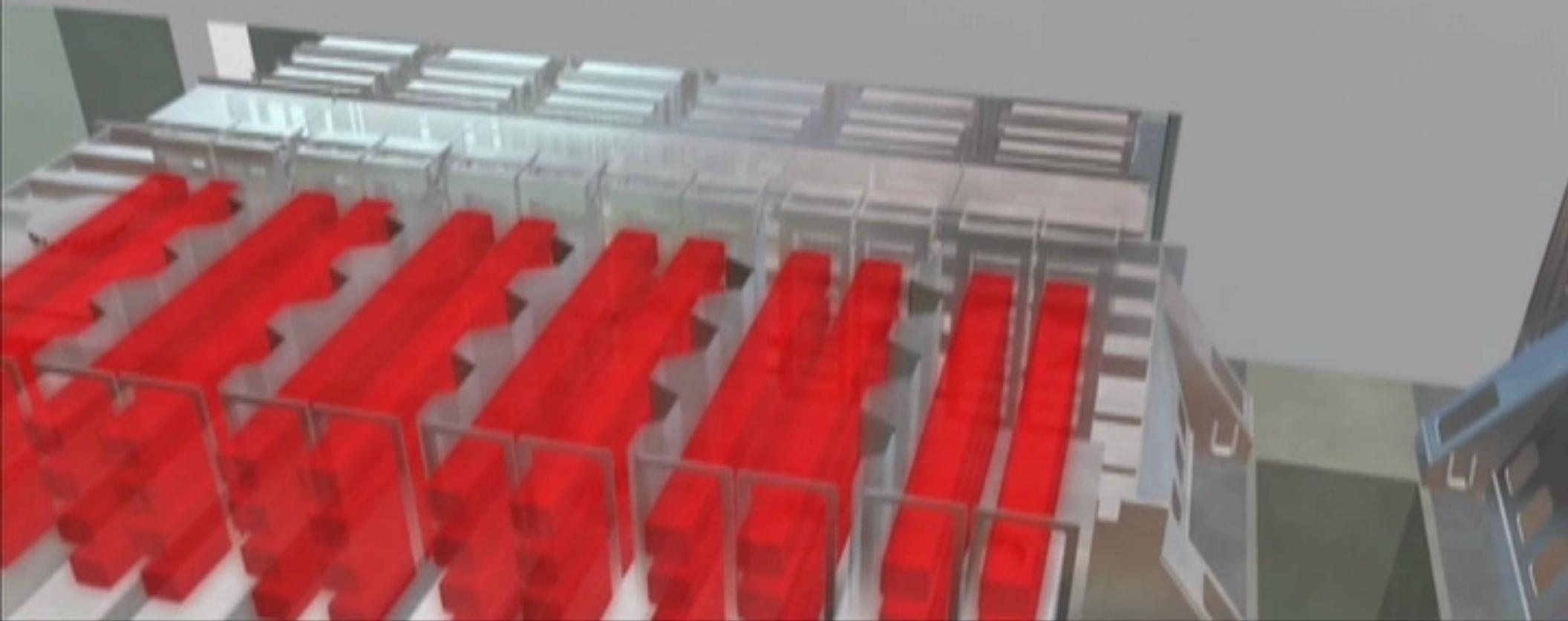
cea

NSTec

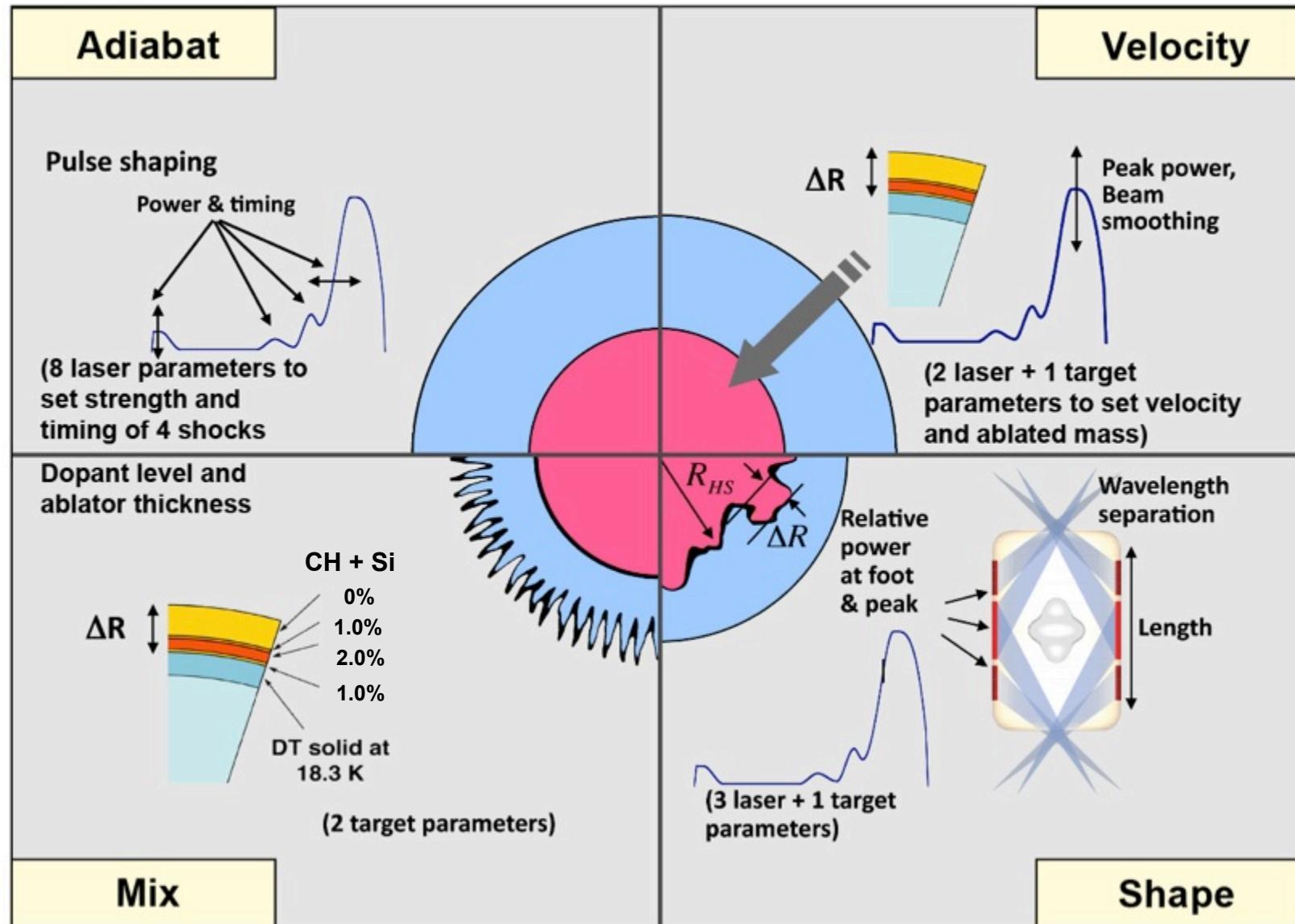


**Duke
UNIVERSITY**

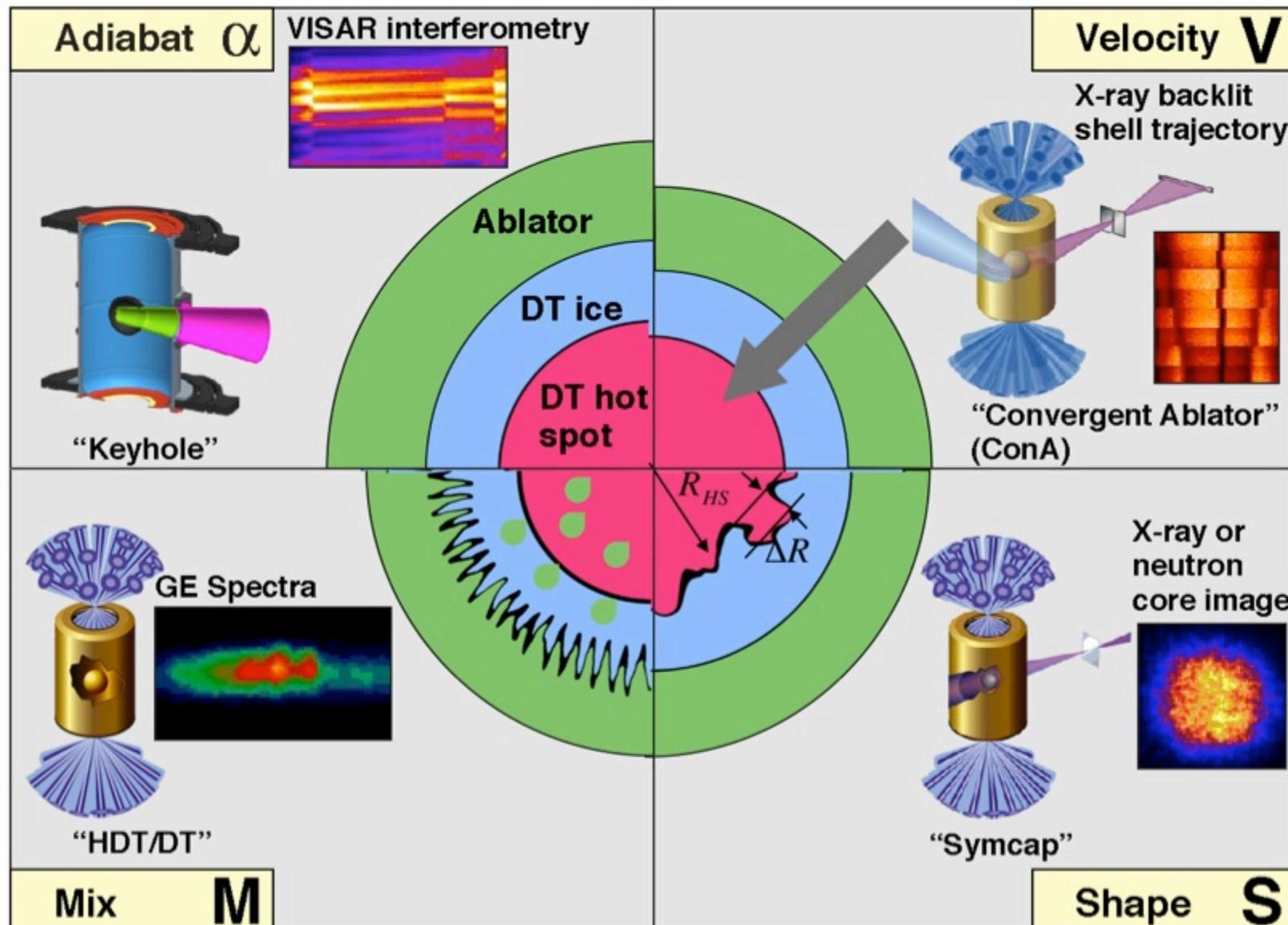




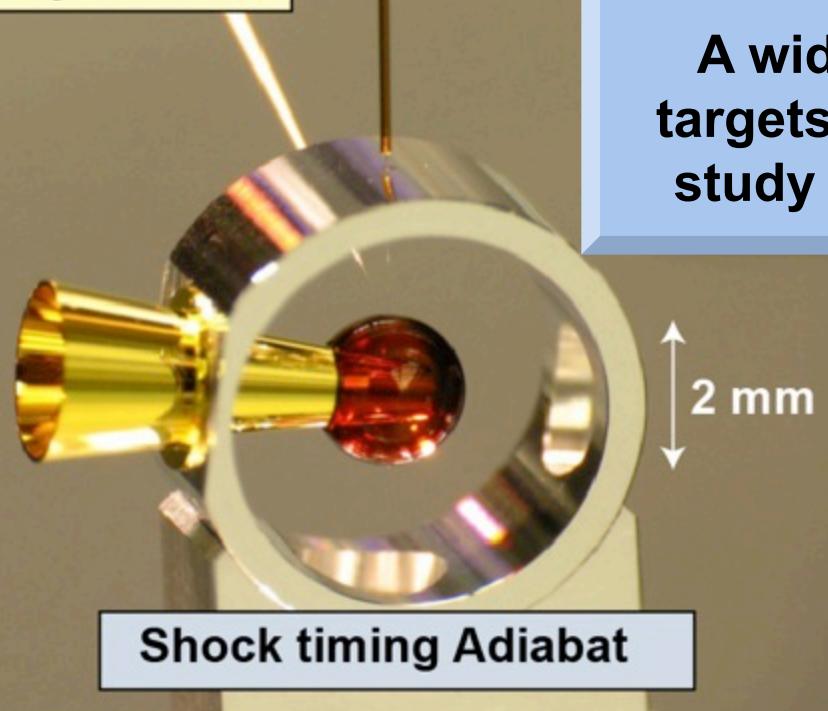
NIC performance is optimized around four key variables



We use a variety of platforms to tune the capsule shape, adiabat, velocity and mix



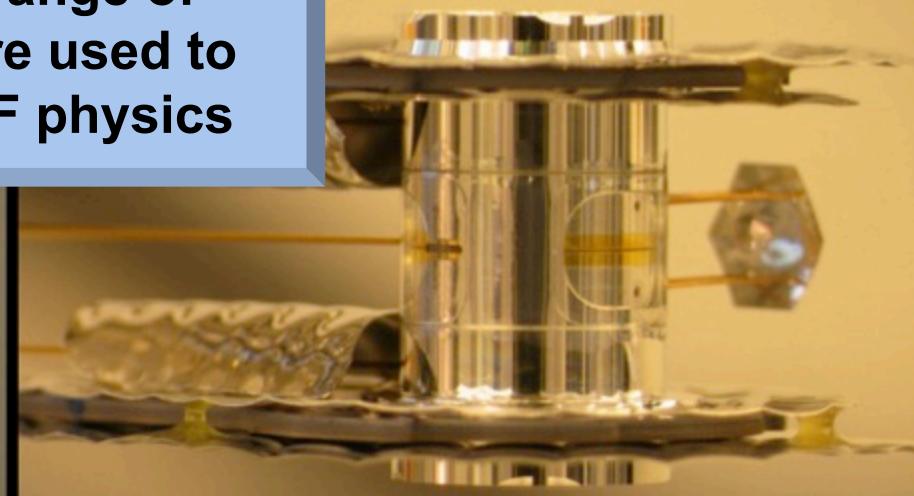
Keyhole



Shock timing Adiabat

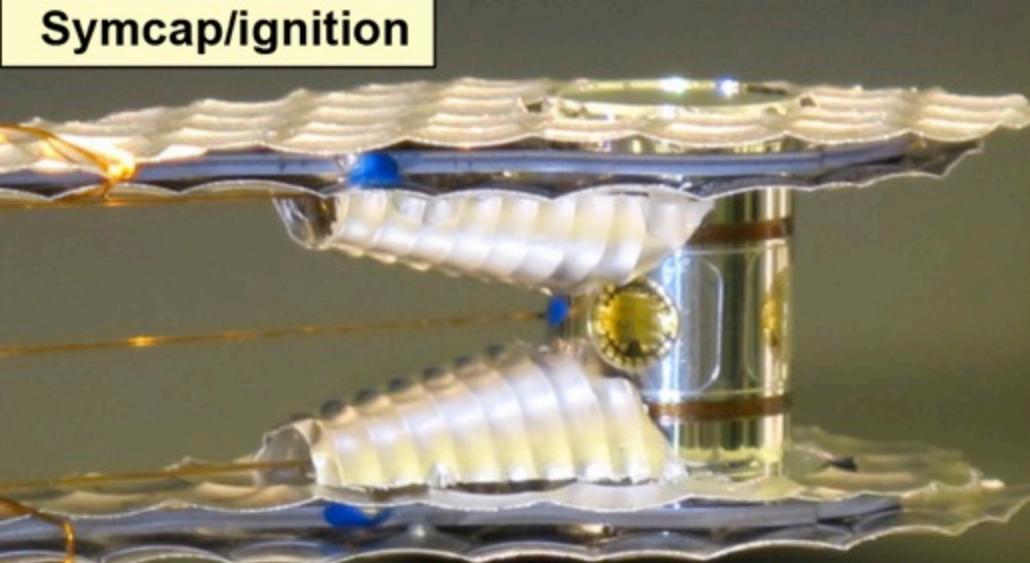
A wide range of targets are used to study ICF physics

Con A



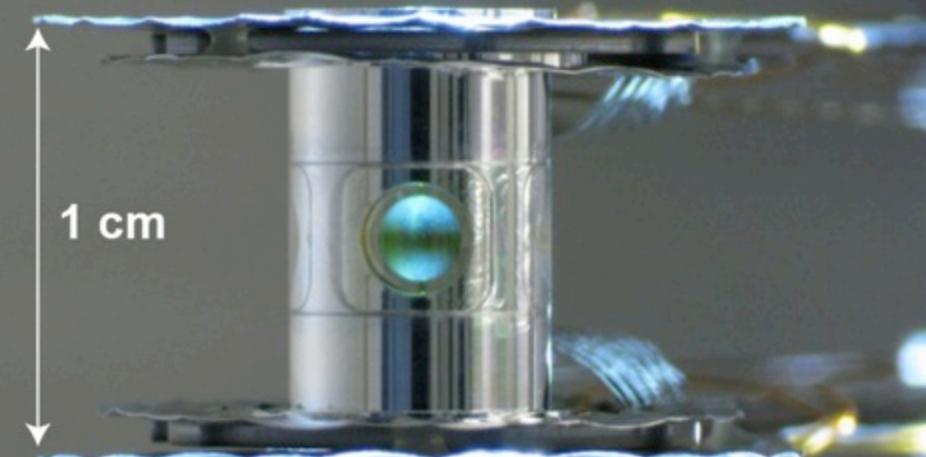
Convergent ablator velocity

Symcap/ignition



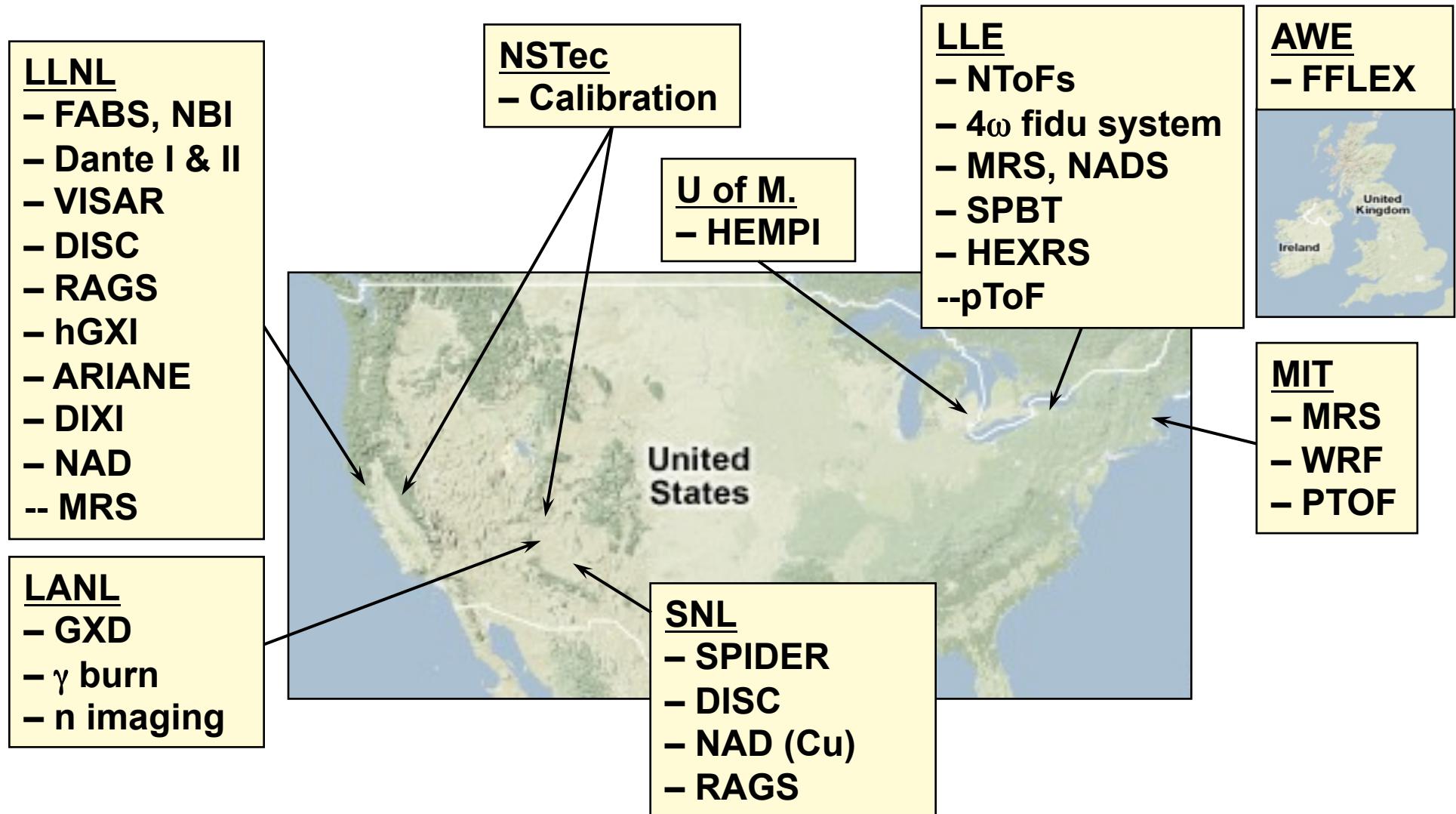
**Symmetry capsule/
ignition mix, shape, yield**

Re-emit



Re-emission shape

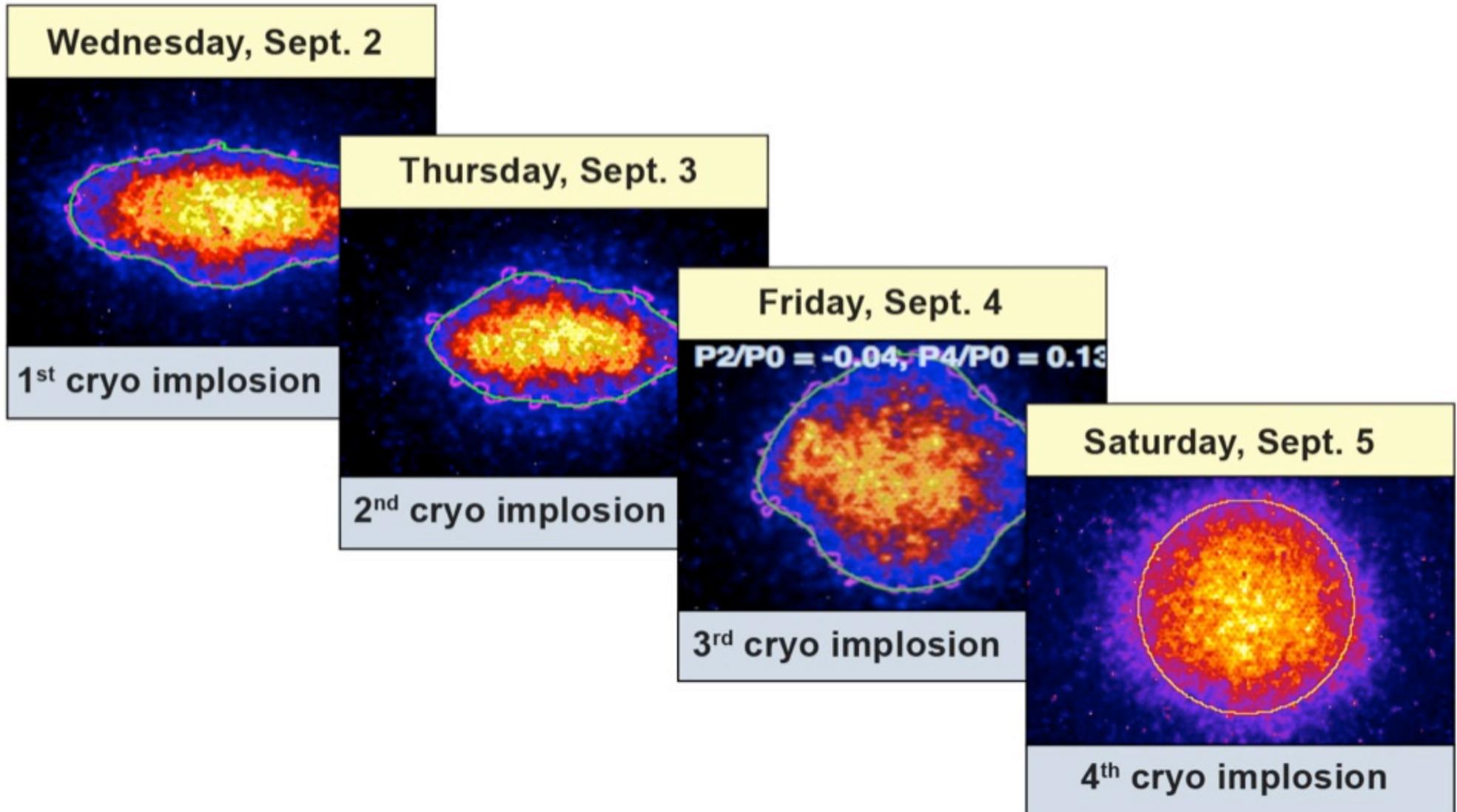
NIF Target diagnostics have helped build the user community – about 50 have been fielded to date



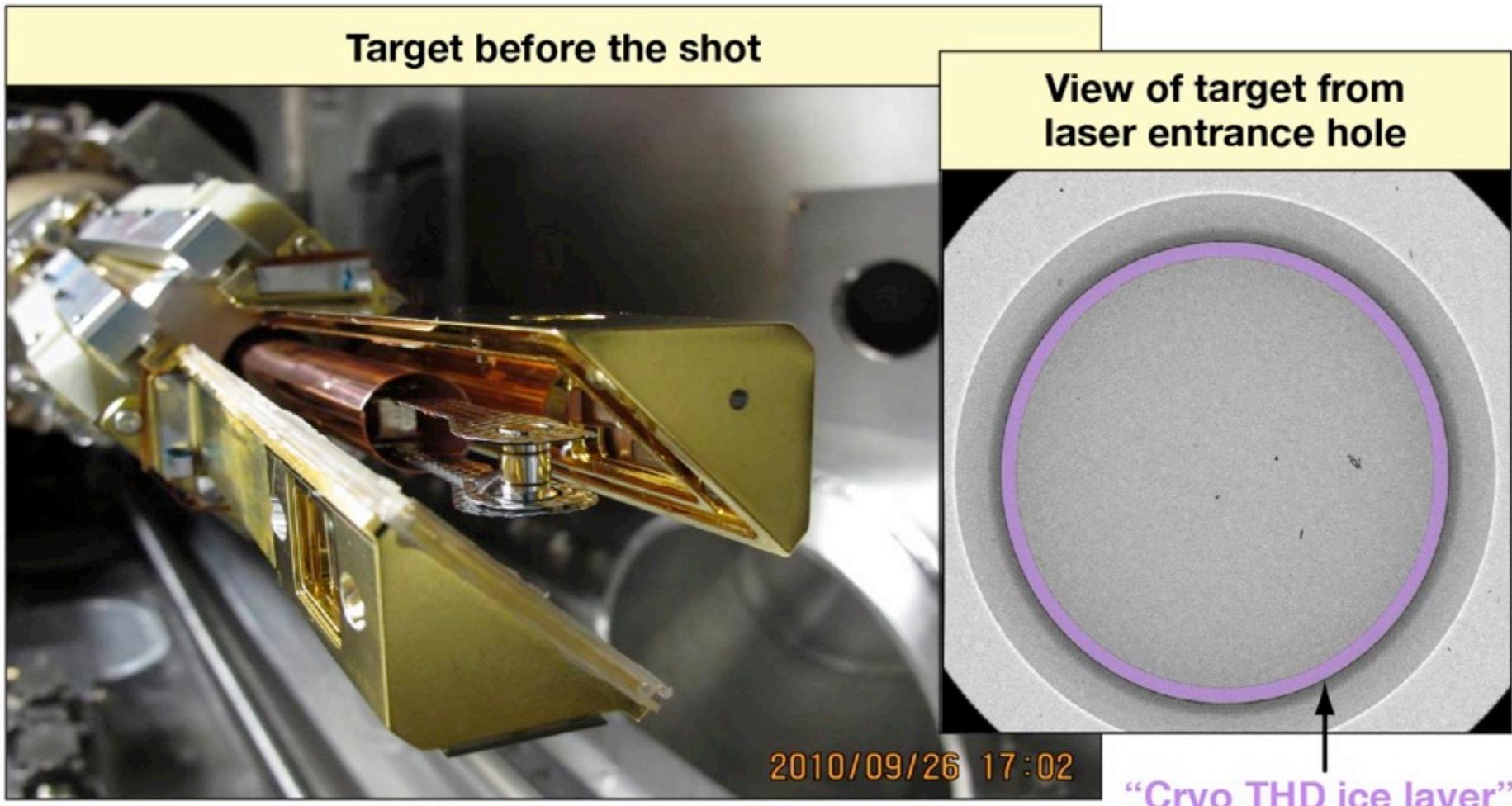
Secretary Chu



On September 2, 2009 NIF conducted its first integrated hohlraum experiments



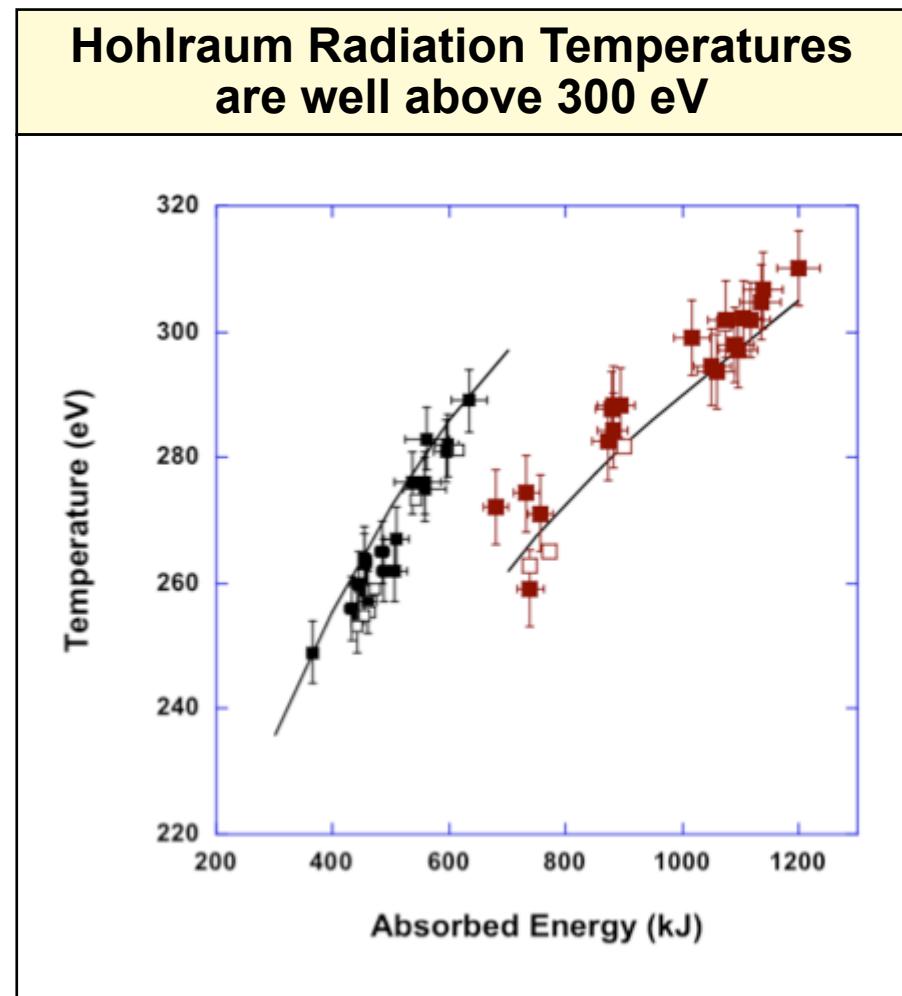
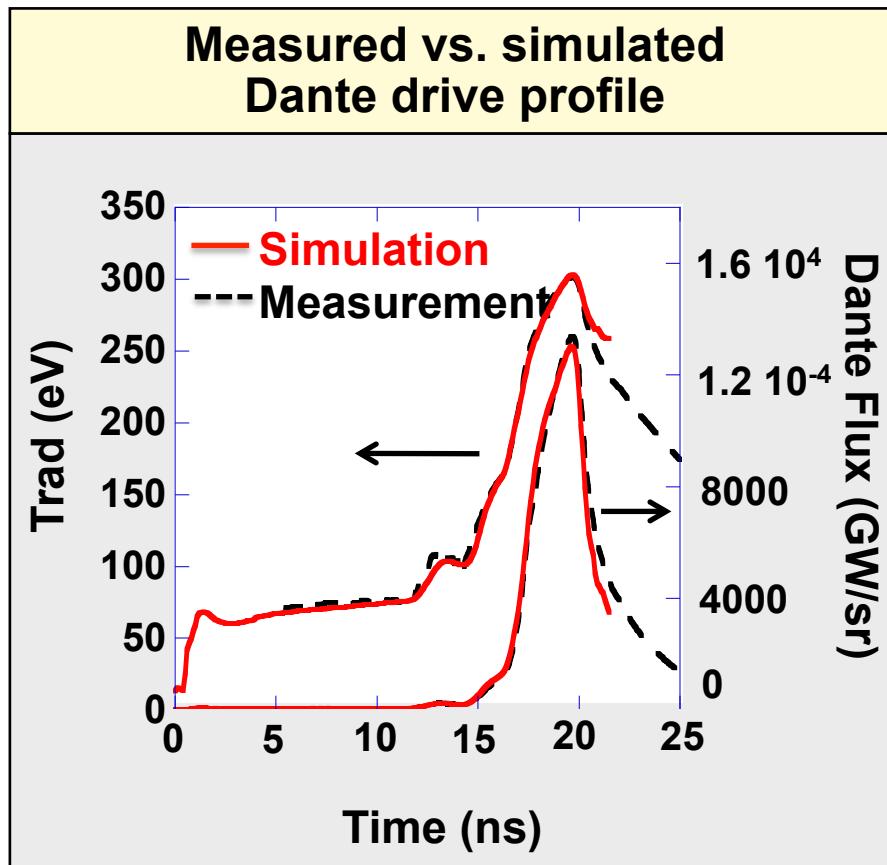
On September 29, 2010 NIC conducted the first cryo-layered target experiment on NIF



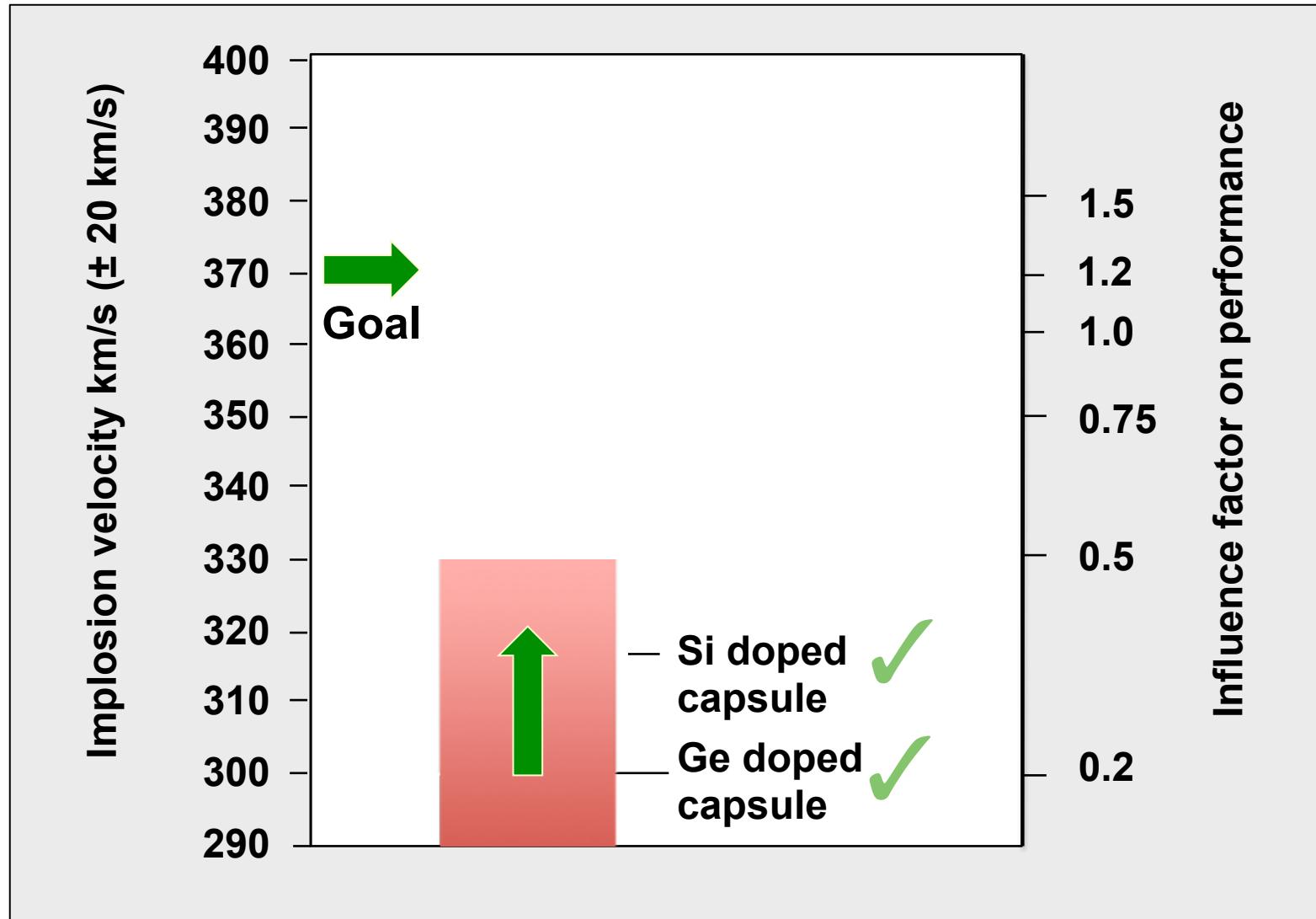
Precision tuning experiments started in May 2011

The required hohlraum temperatures have been achieved, with LPI under sufficient control

- LPI observed to be at level acceptable for ignition experiments
- Detailed dependencies different to expectations, but reproducible and tunable

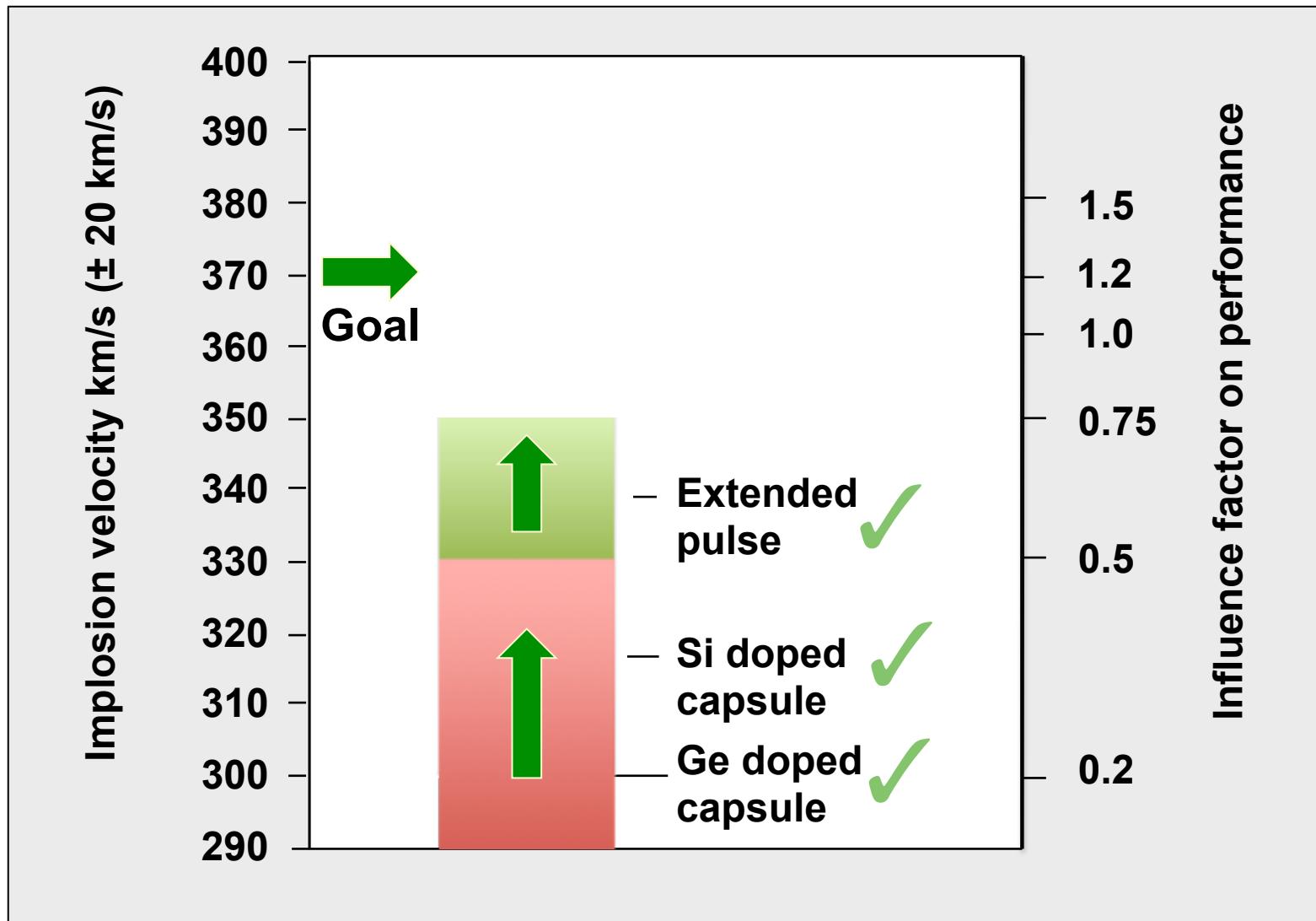


Velocity: progression from substantial deficit to an excess that can be traded against mix susceptibility



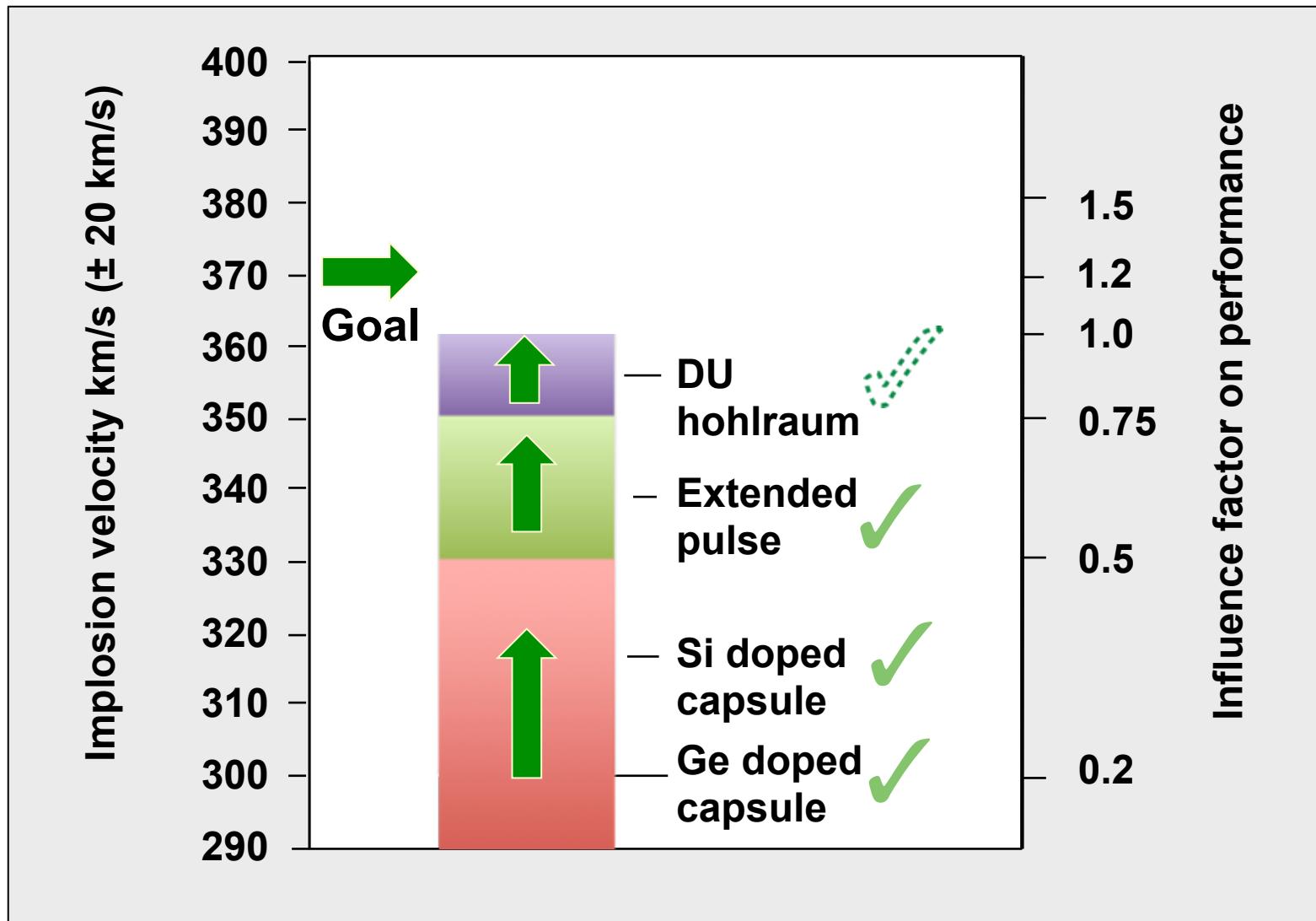
Hydrodynamic instability growth and velocity need to be balanced

Velocity: progression from substantial deficit to an excess that can be traded against mix susceptibility



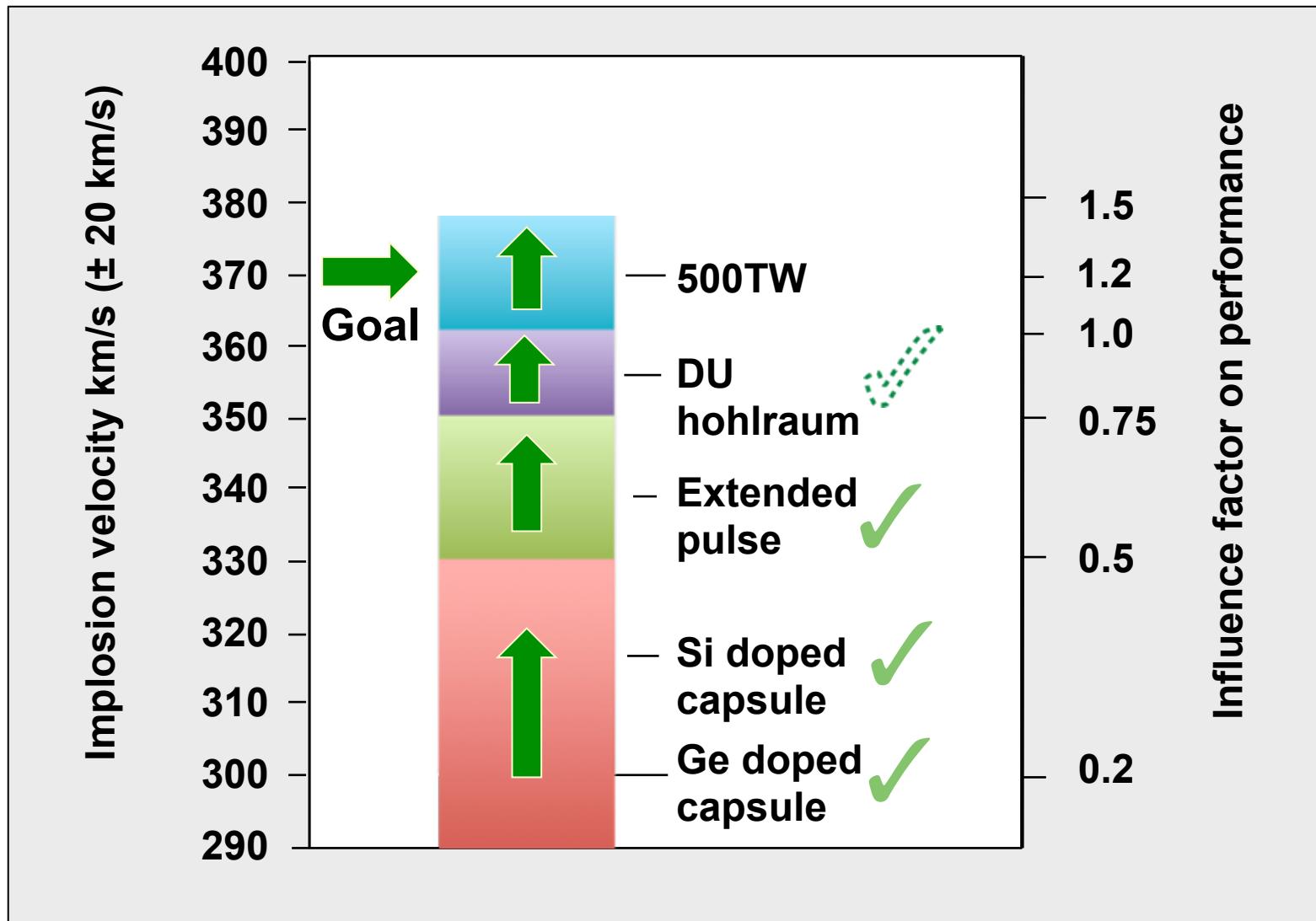
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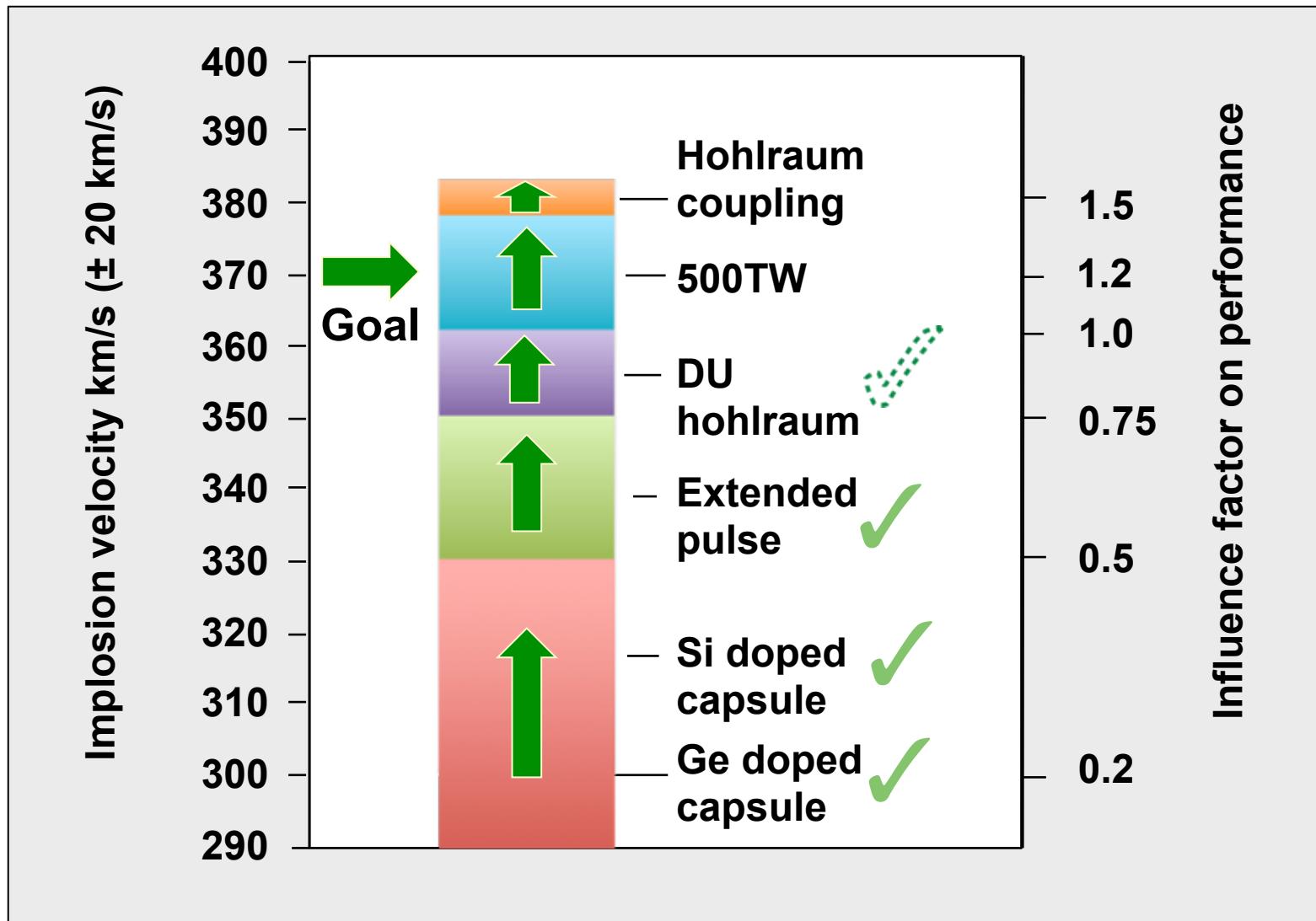
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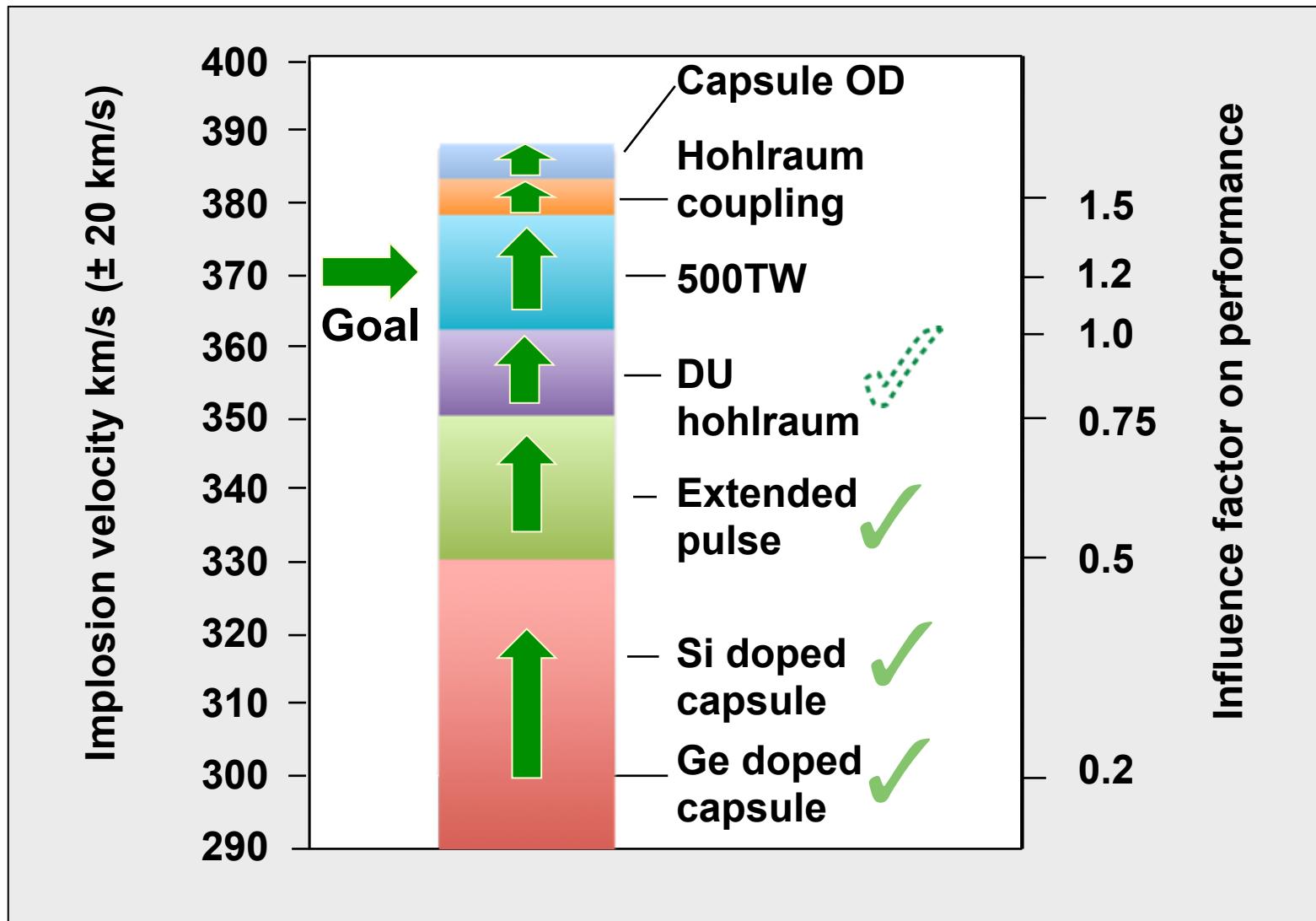
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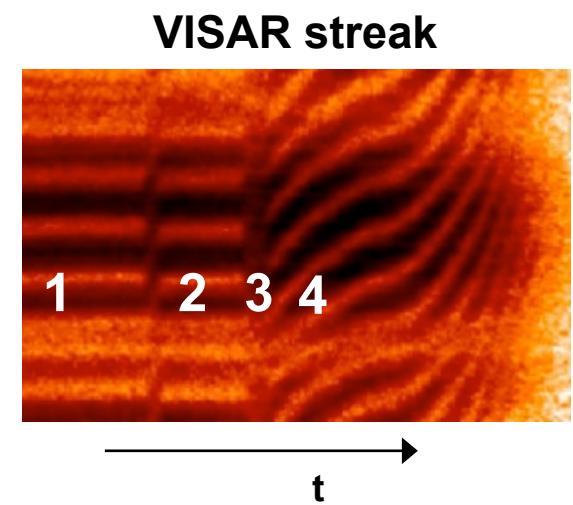
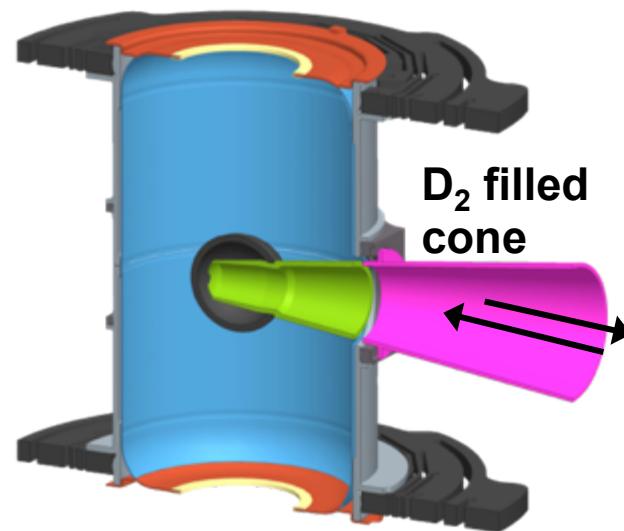
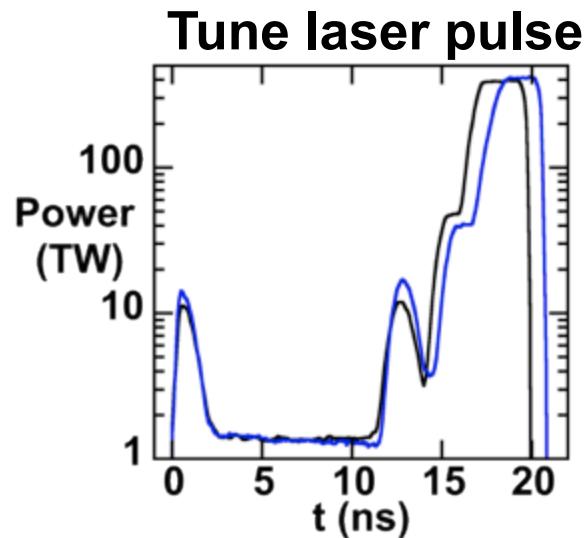
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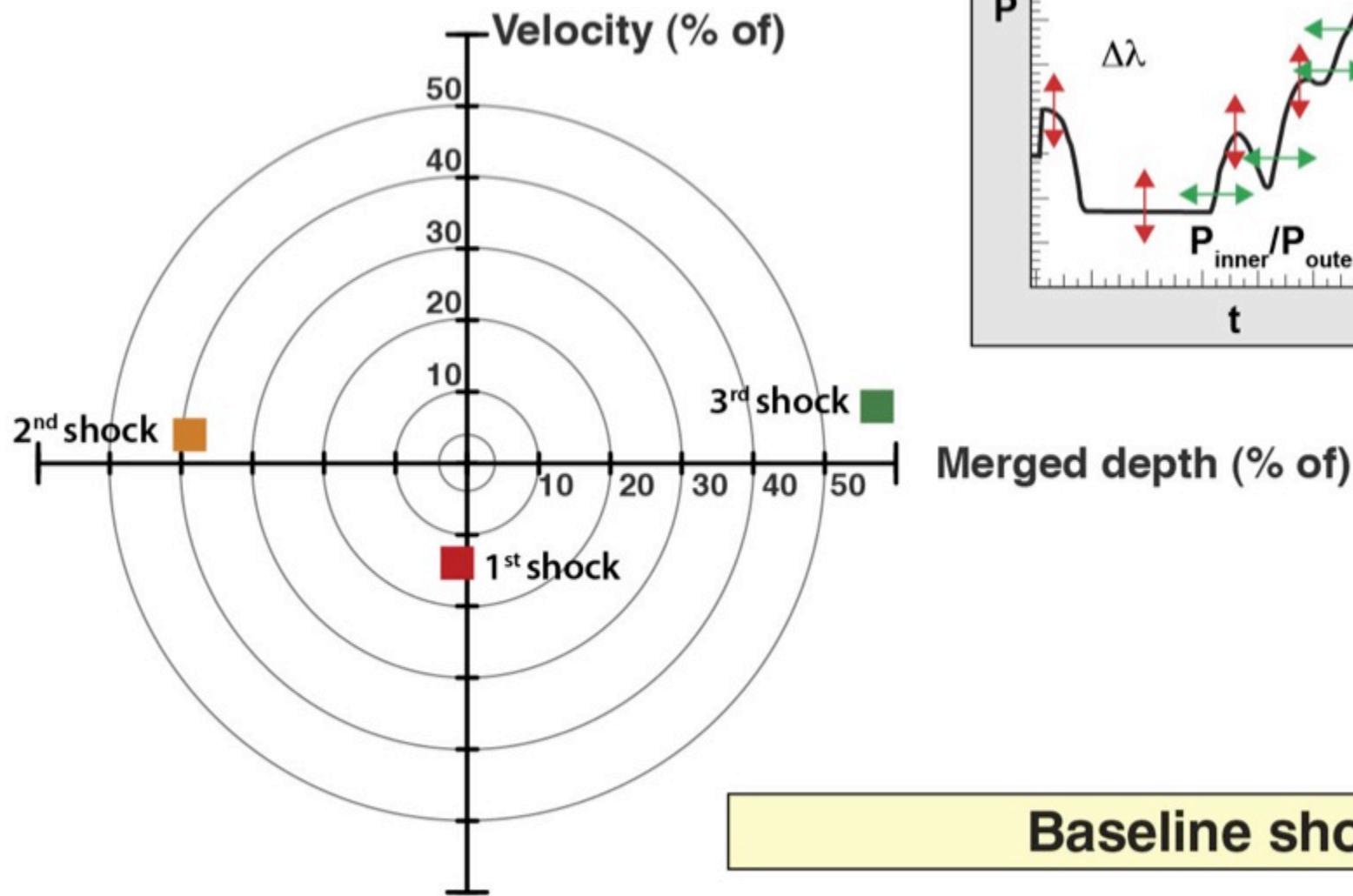


Hydrodynamic instability growth and velocity need to be balanced

Adiabat: controlled via timing the 4-shocks;
measured using a “keyhole target”

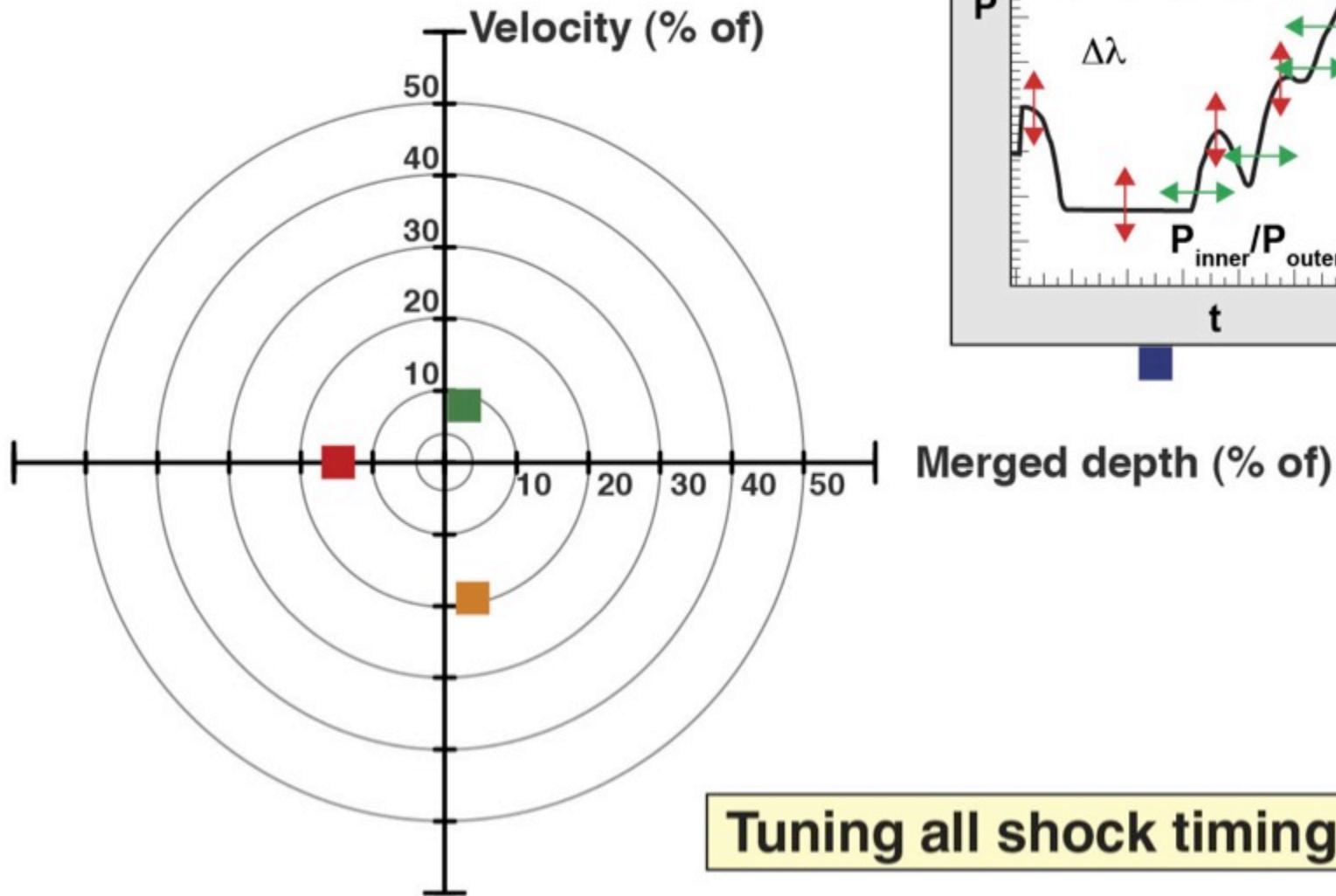


Adiabat: Shocking timing shot A



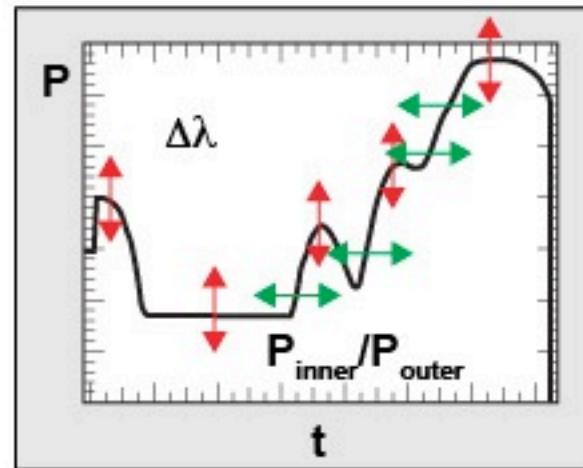
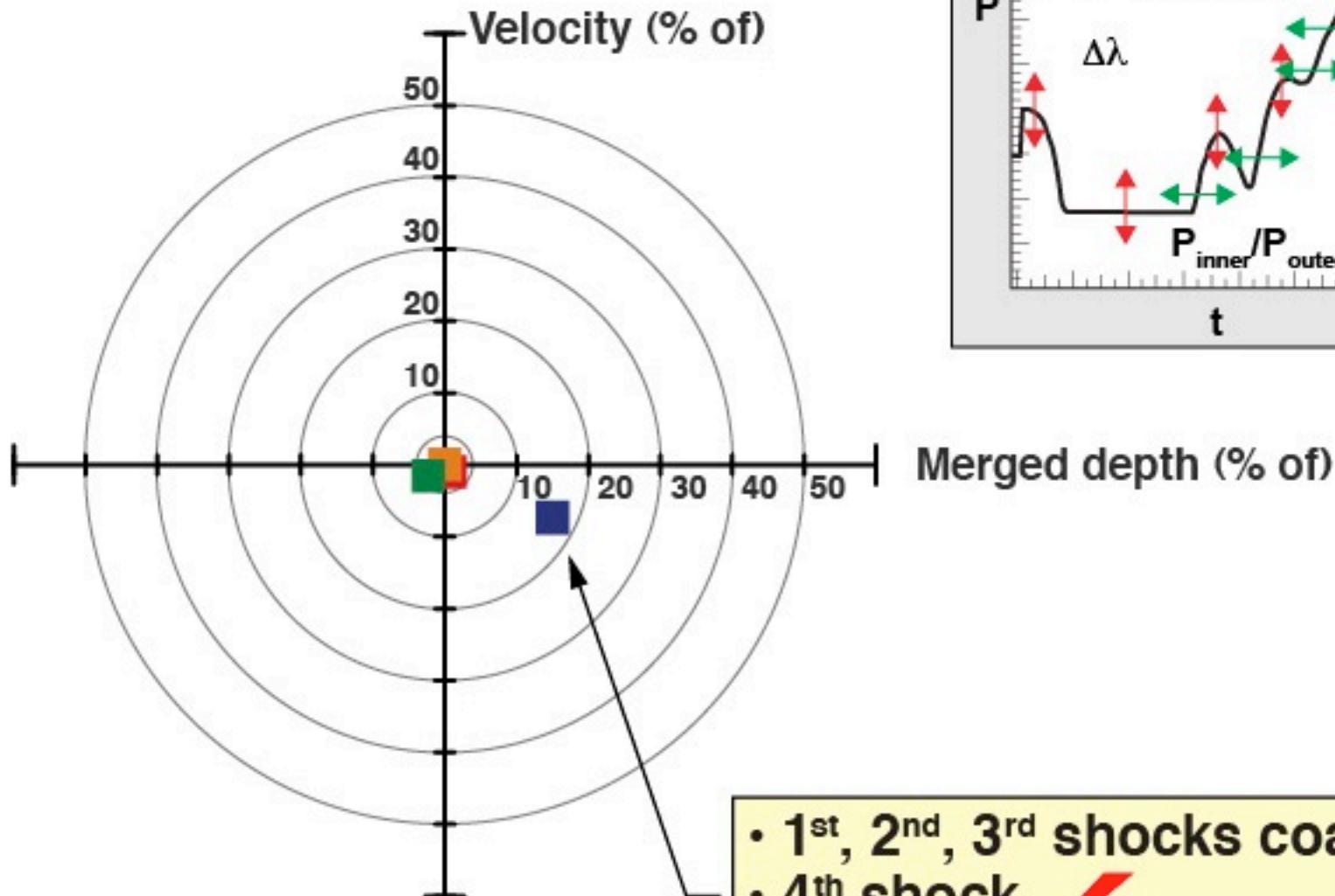
Baseline shot

Adiabat: Shock timing shot B

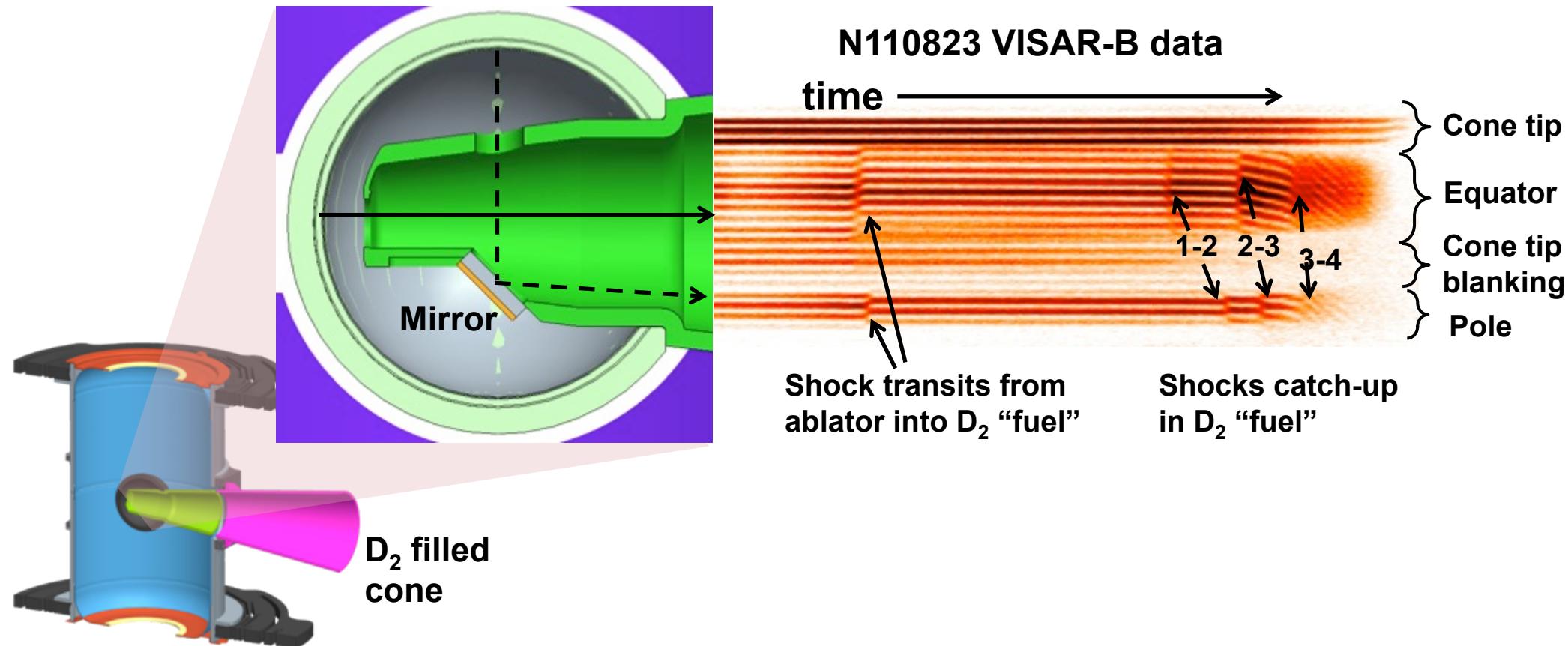


Tuning all shock timing / amplitude

Adiabat: Shock timing shot C

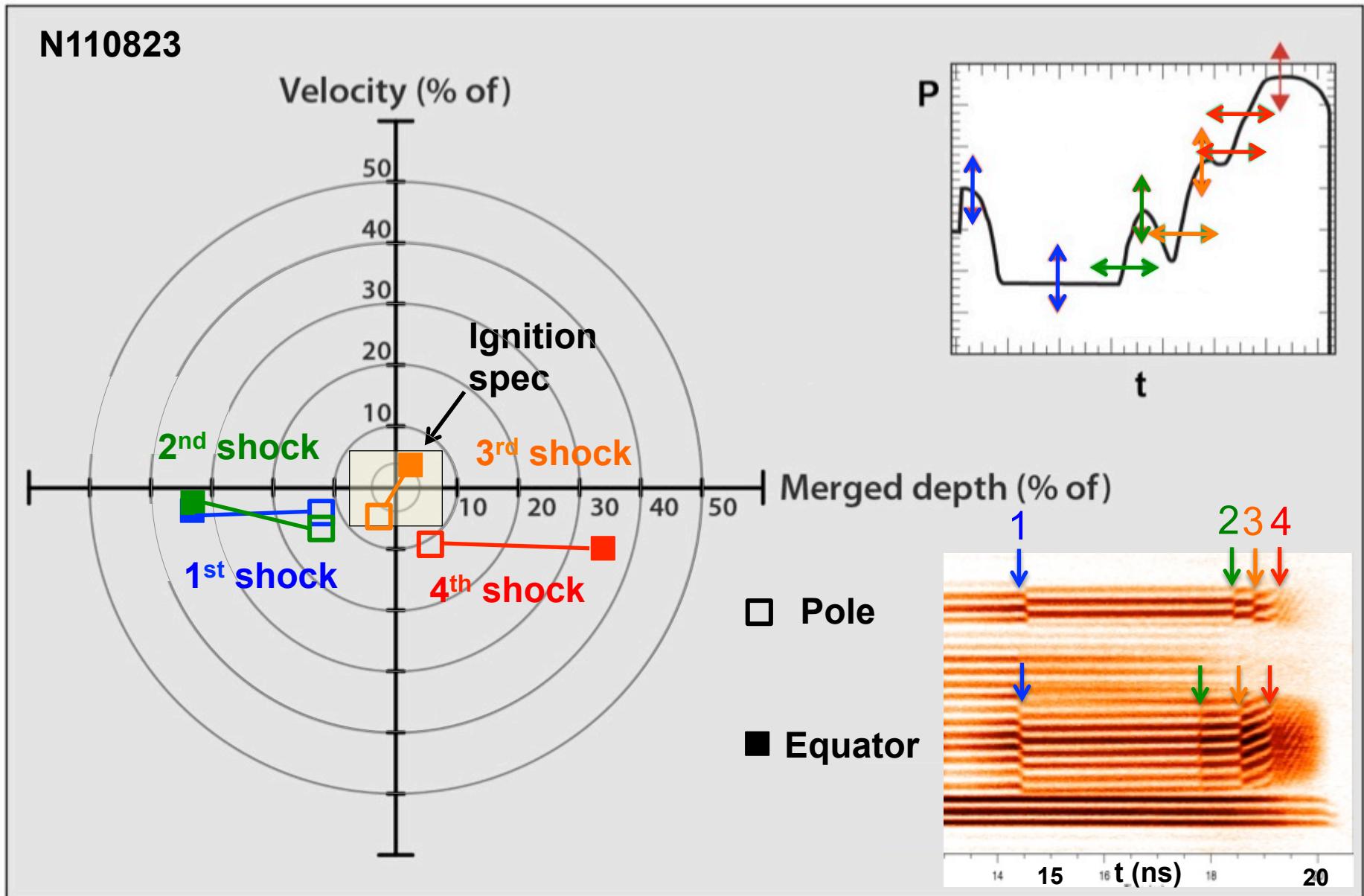


Adiabat: New diagnostic added to monitor shock symmetry

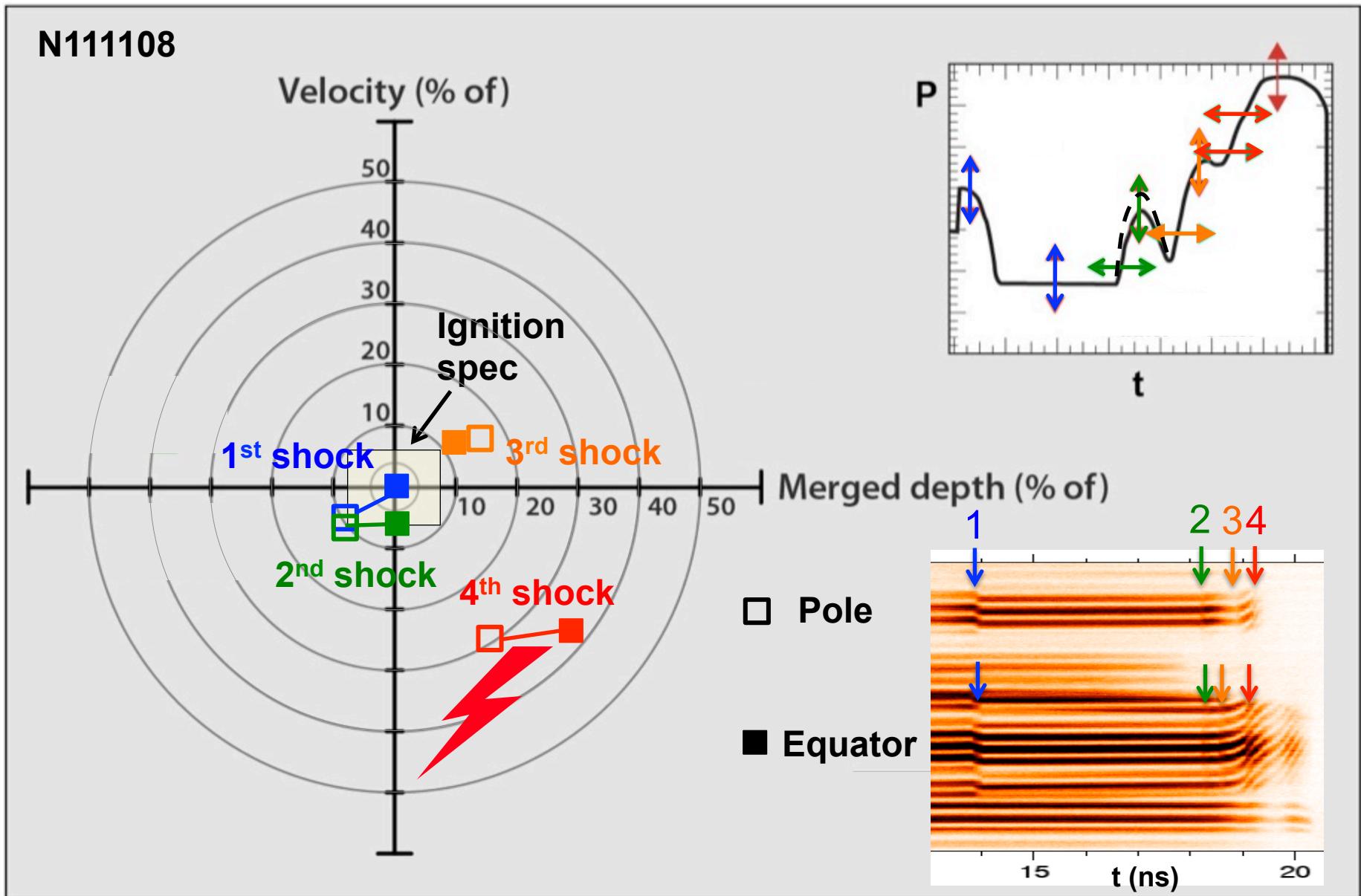


- Velocity was 5-10% low on the pole
- The October 2011 campaign used the mirrored keyhole to correct time dependent asymmetry

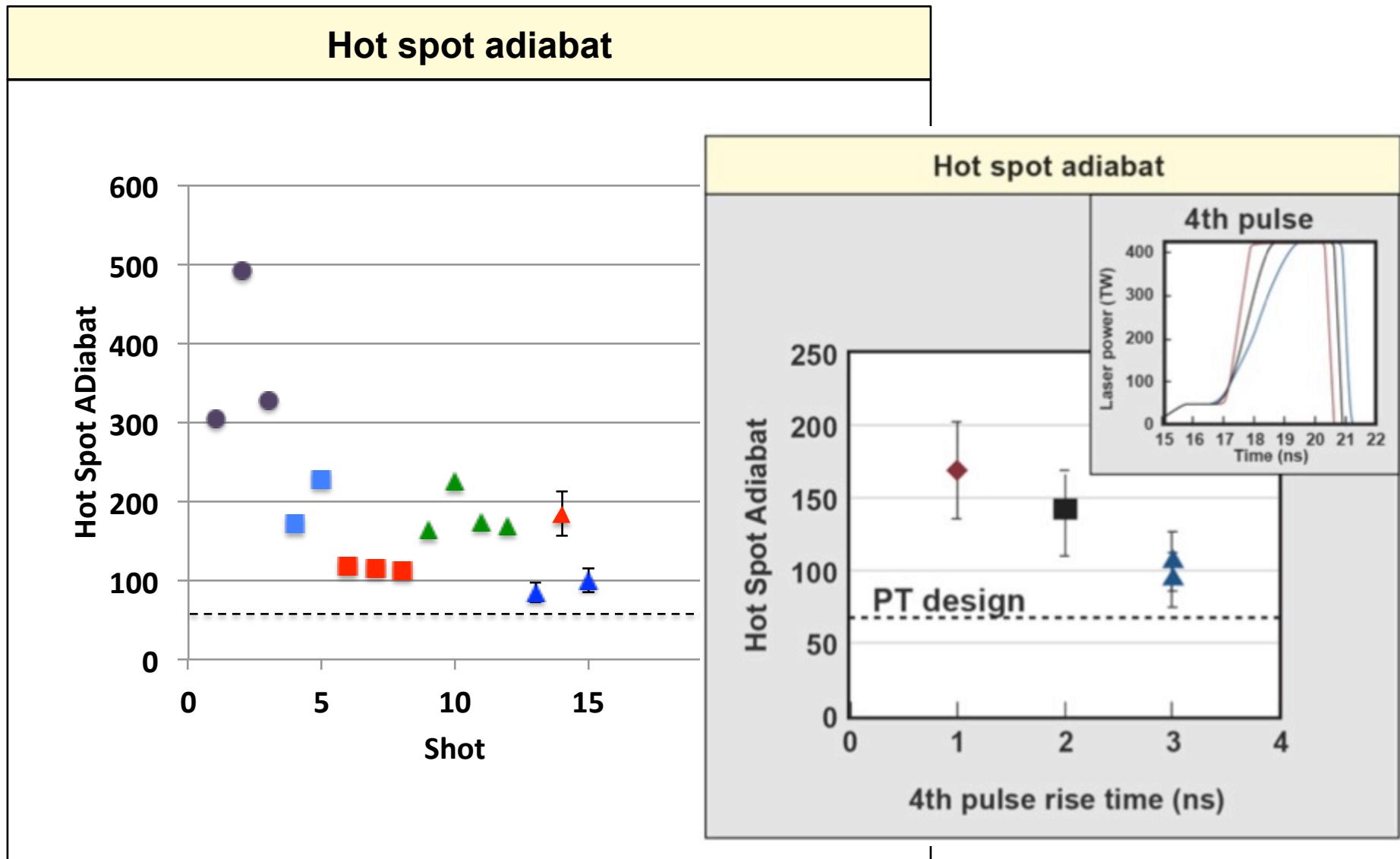
August 2011 - Equator vs. pole asymmetries in shock velocities and merge depths exceeded ignition tolerance



November 2011: Symmetrized shock within ignition tolerance by setting independent inner and outer cone 2nd pulse powers

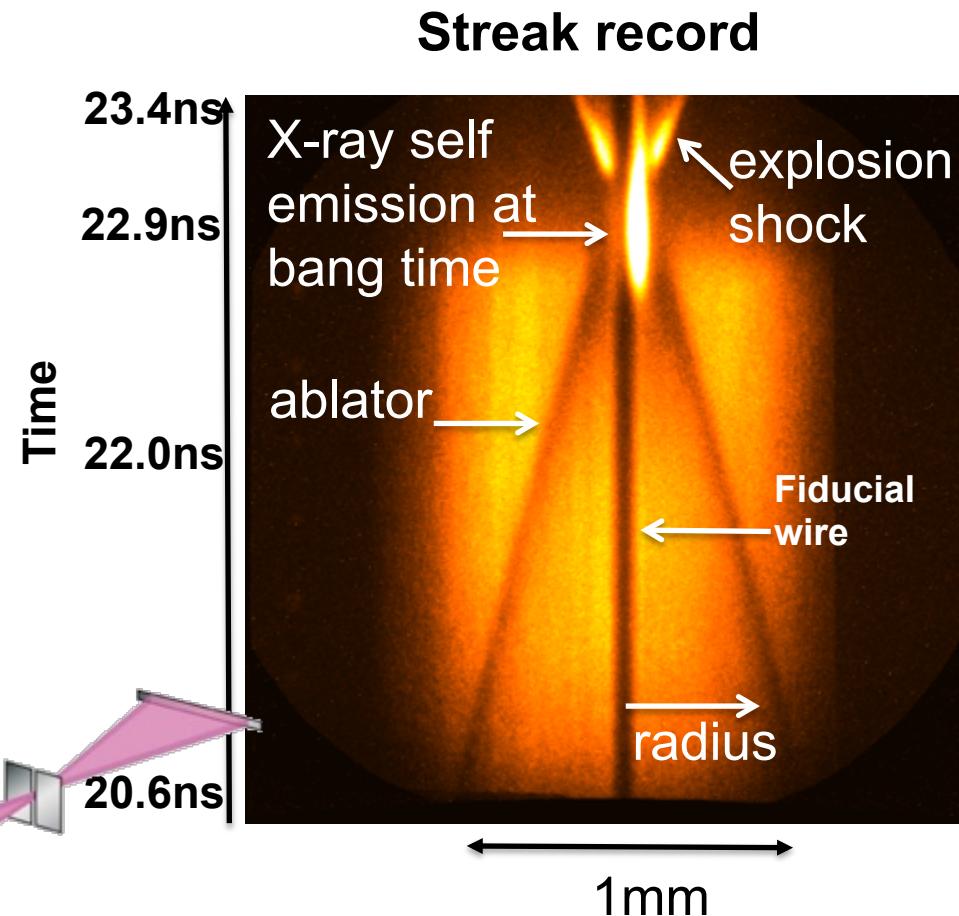
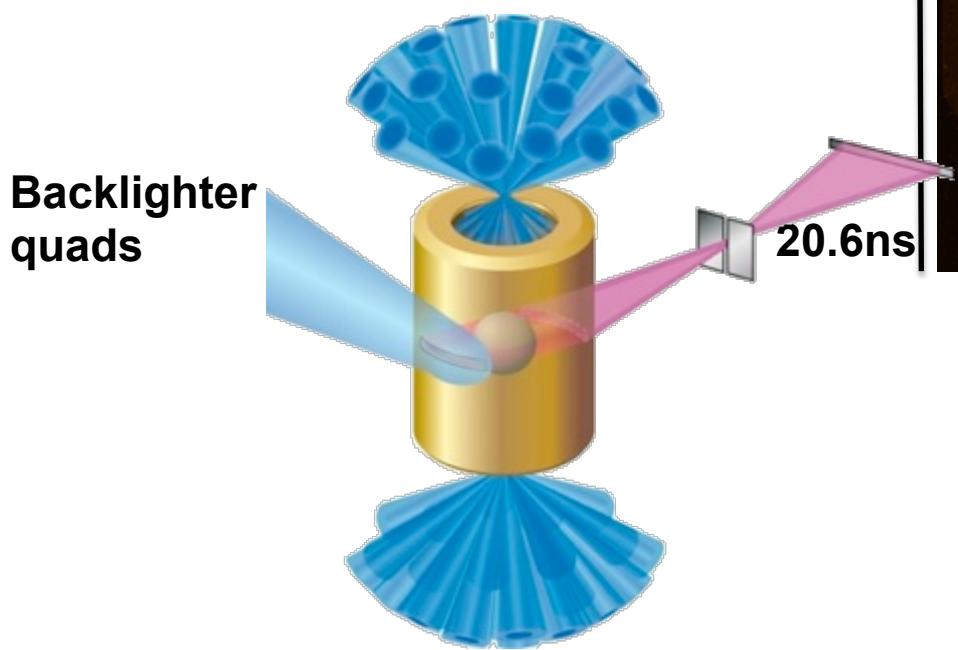


Hot spot adiabat is approaching point design conditions with slow rise 4th pulse



Commissioned streaked backlit diagnosis to further improve implosion performance

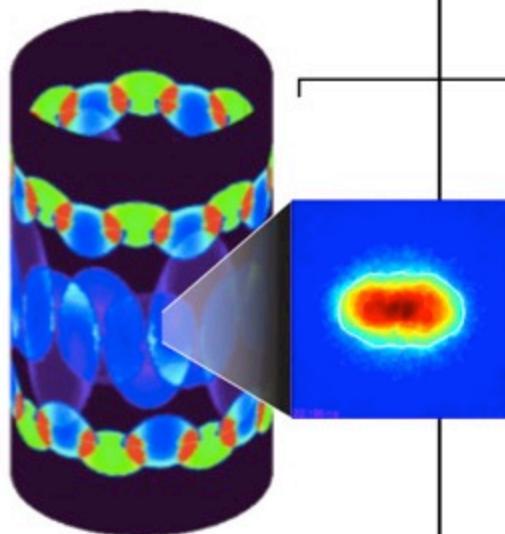
- Provides continuous record of 1D ablator physics - trajectory, width, mass



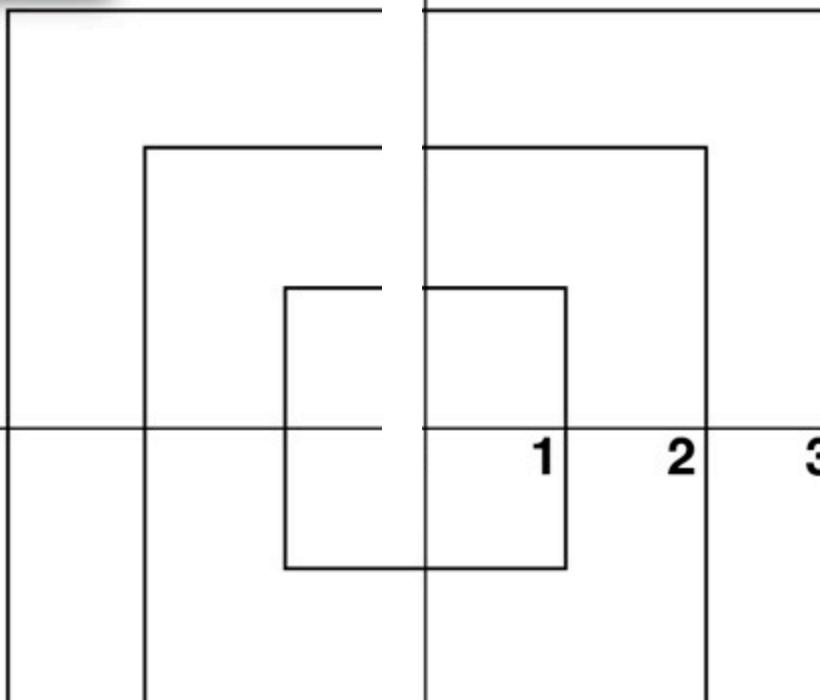
**Implosion
symmetry – P2
“2-color tuning or λ_2 ”**

$$P_2 = \frac{1}{2}(3\cos^2 \theta - I)$$

“Pancake”

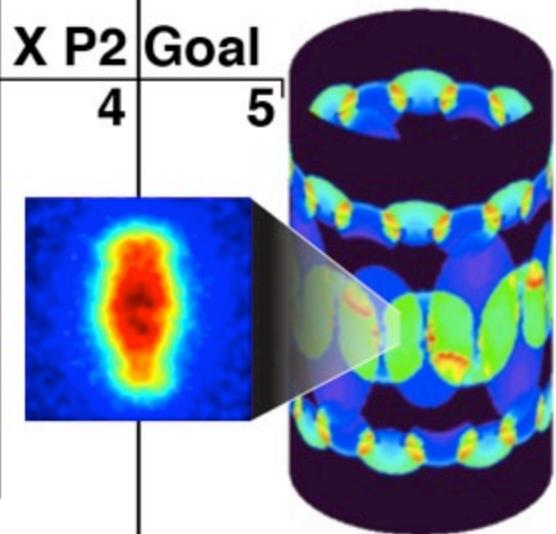


**Inner beams
less bright**



X P2 Goal

“Sausage”



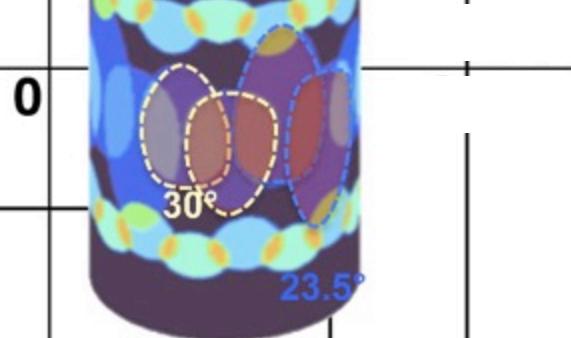
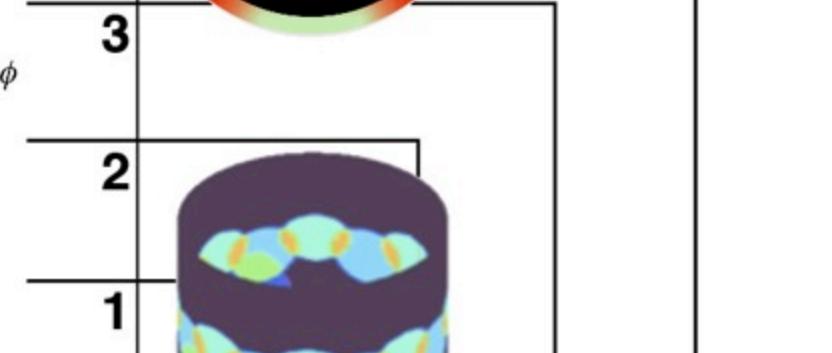
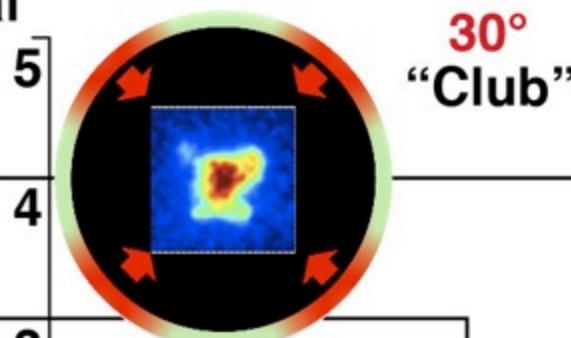
**Inner beams
more bright**

X M4 Goal

Implosion symmetry – “M4”
“3-color tuning or λ_3 ”

$$Y_l^m(\theta, \phi) = \sqrt{\frac{2l+1}{4\pi}} \frac{(l-m)!}{(l+m)!} P_l^m(\cos\theta) e^{im\phi}$$

$$Y_4^4(\theta, \phi) = 105 \sqrt{\frac{9}{4\pi}} \sin^4 \theta e^{i4\phi}$$

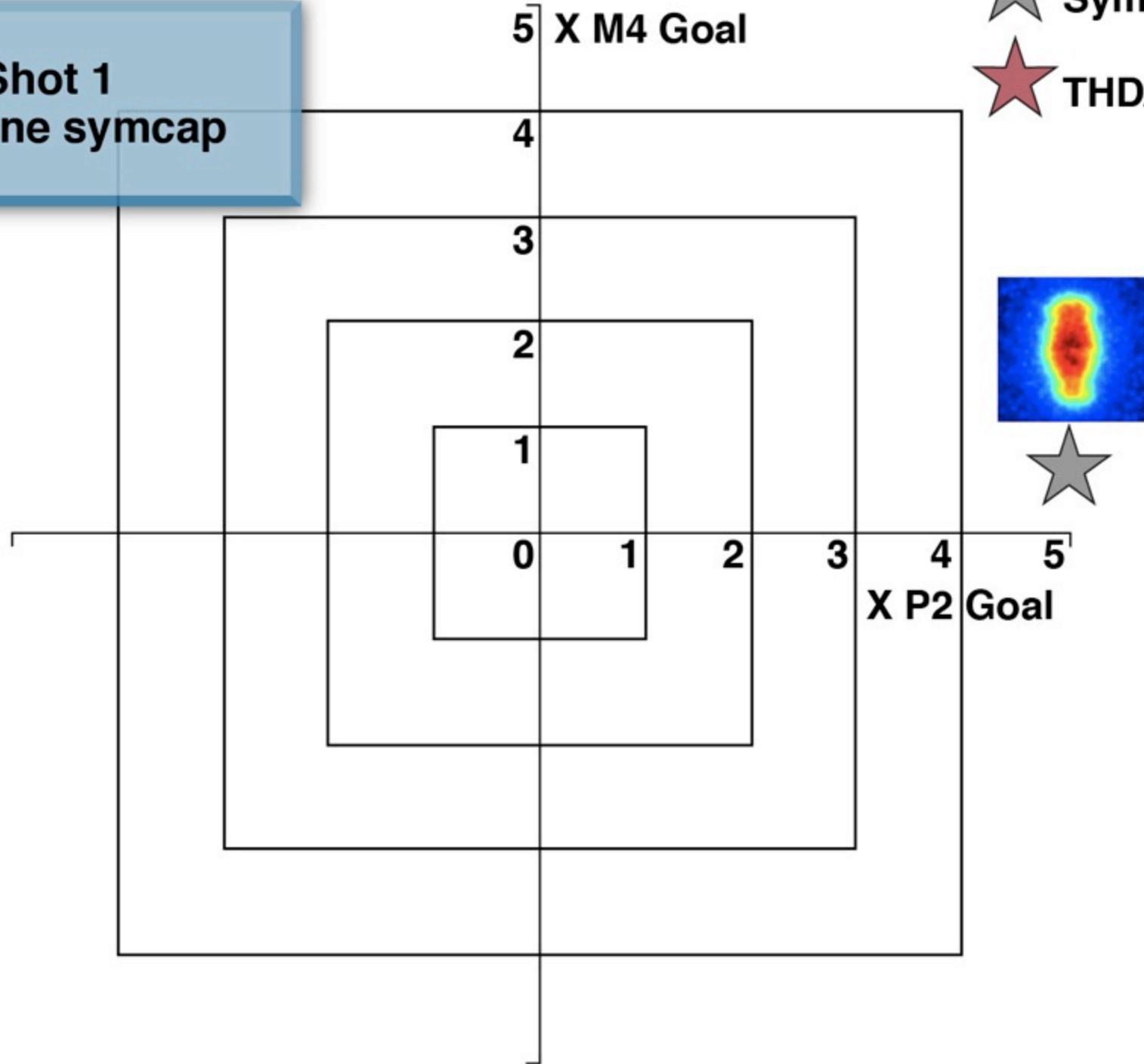


“Diamond”

Shot 1
Baseline symcap

5 X M4 Goal

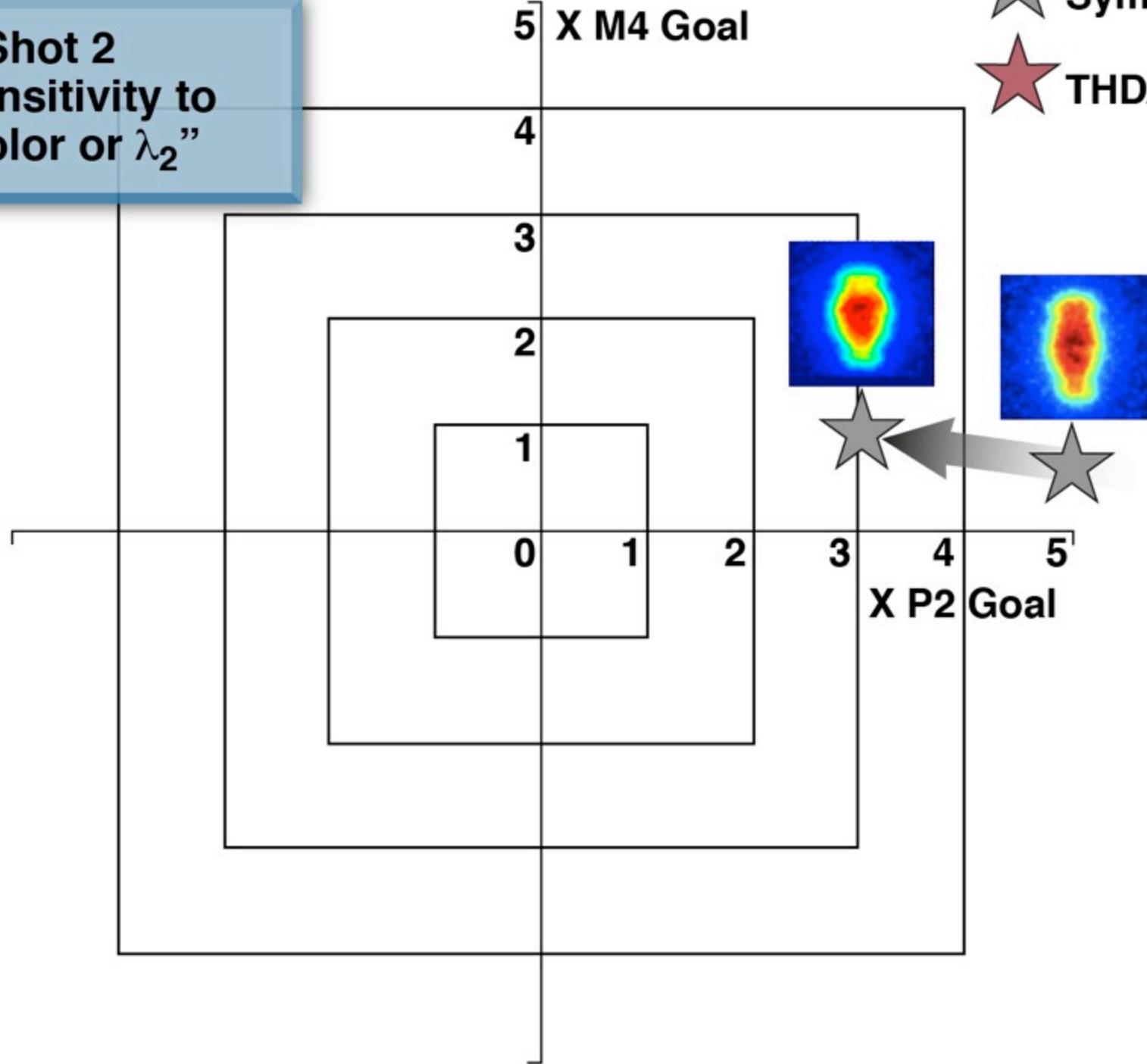
★ Symcap
★ THD/DT



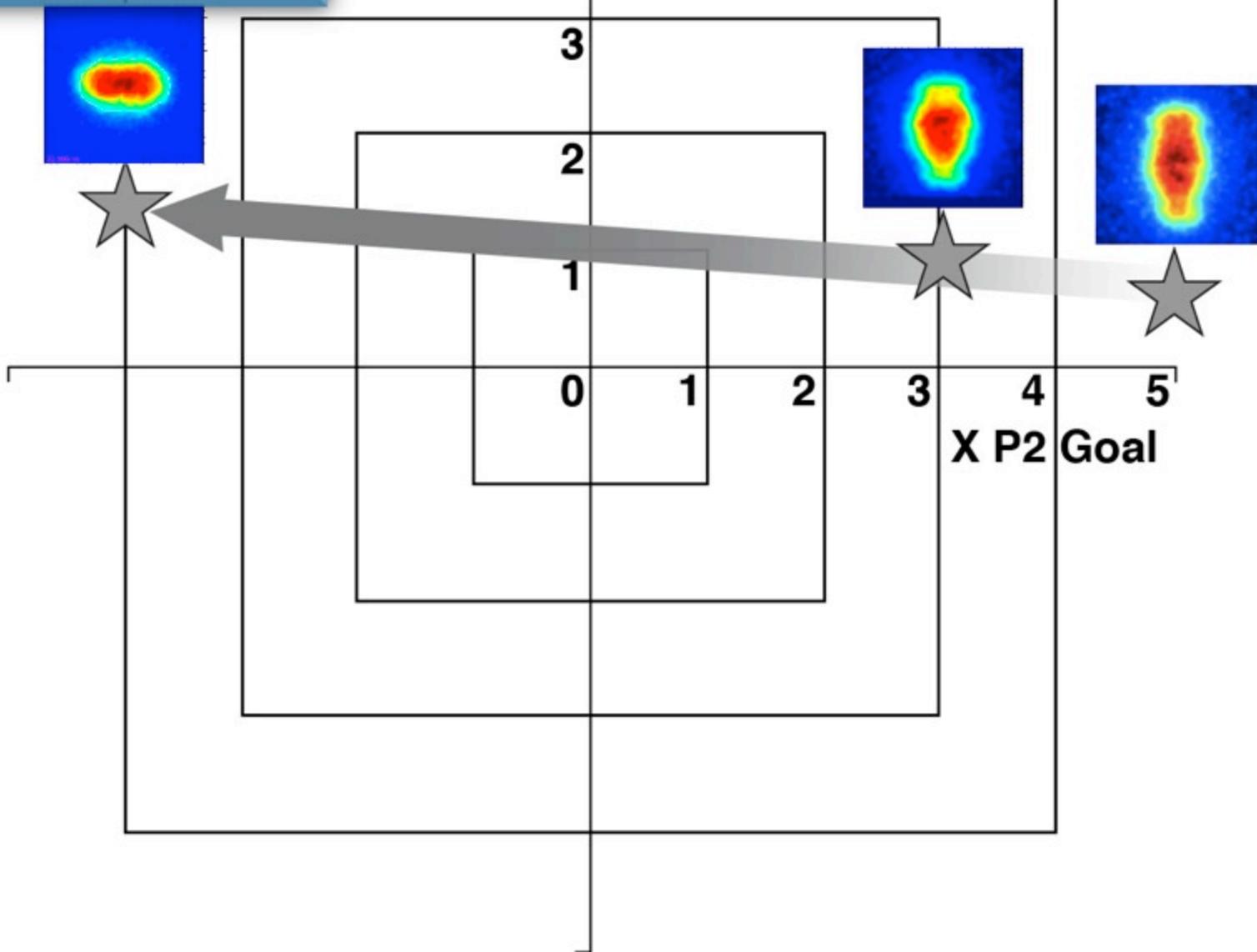
Shot 2
P2 sensitivity to
“2-color or λ_2 ”

5 X M4 Goal

★ Symcap
★ THD/DT

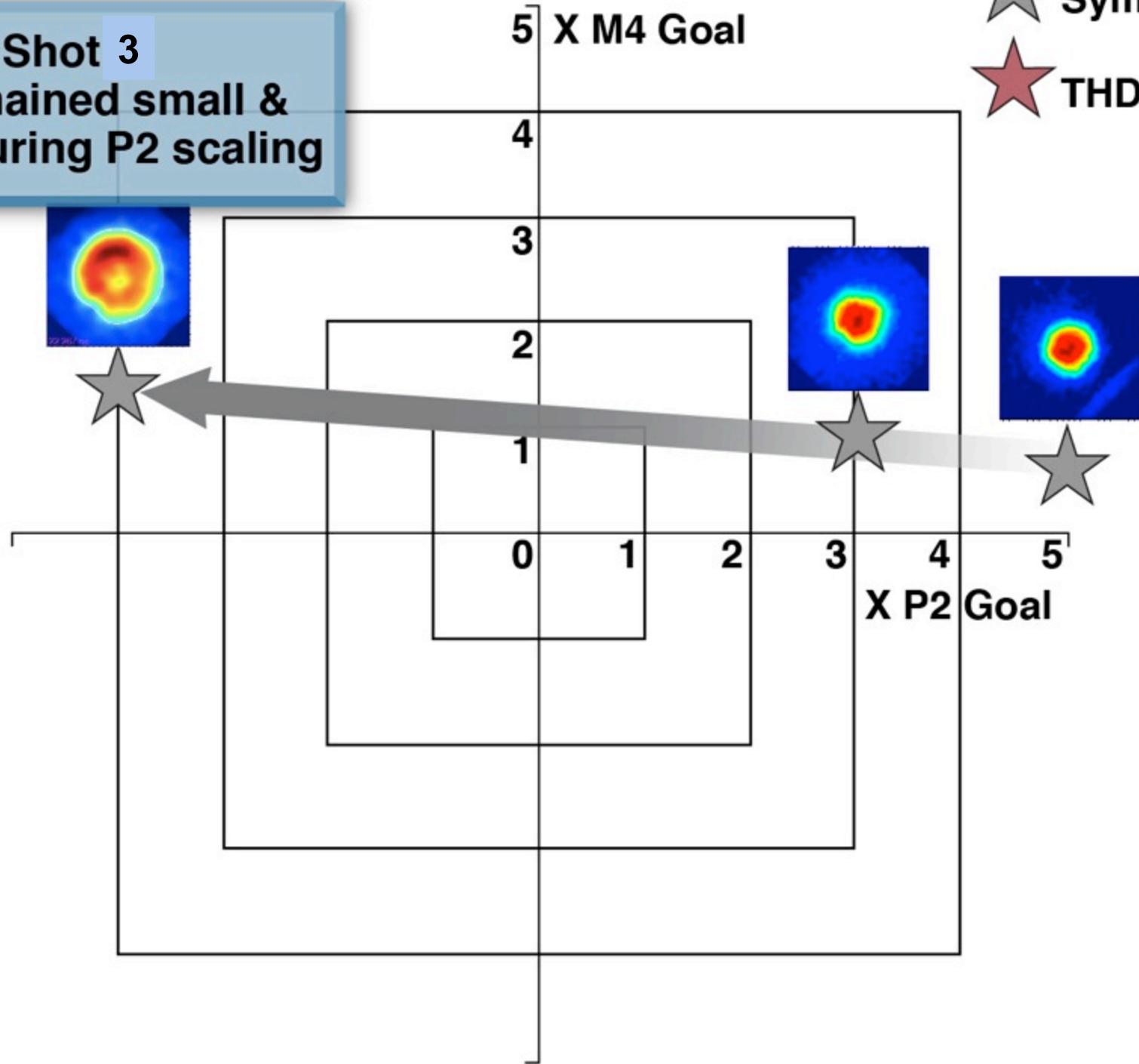


Shot 3
P2 sensitivity to
"2-color or λ_2 "

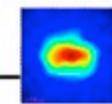
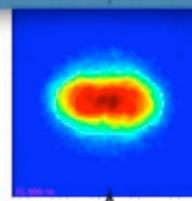


 Symcap
 THD/DT

Shot 3
M4 remained small &
stable during P2 scaling



Shot 4
Tune P2 for THD
-Observed m4



5 X M4 Goal

★ Symcap
★ THD/DT



Surrogacy?

Tuning

1

0

1

2

3

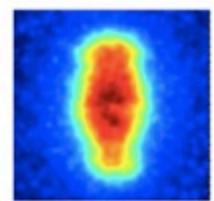
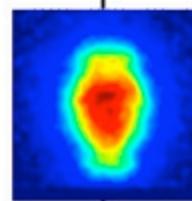
X P2 Goal

4

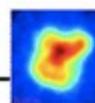
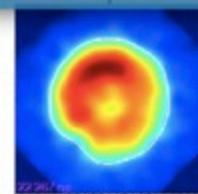
5

3

4



Shot 4
Tune P2 for THD
-Observed m4



5 X M4 Goal

4

3

2

1

0

1

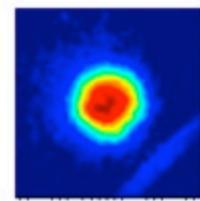
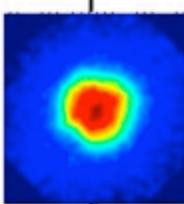
2

3

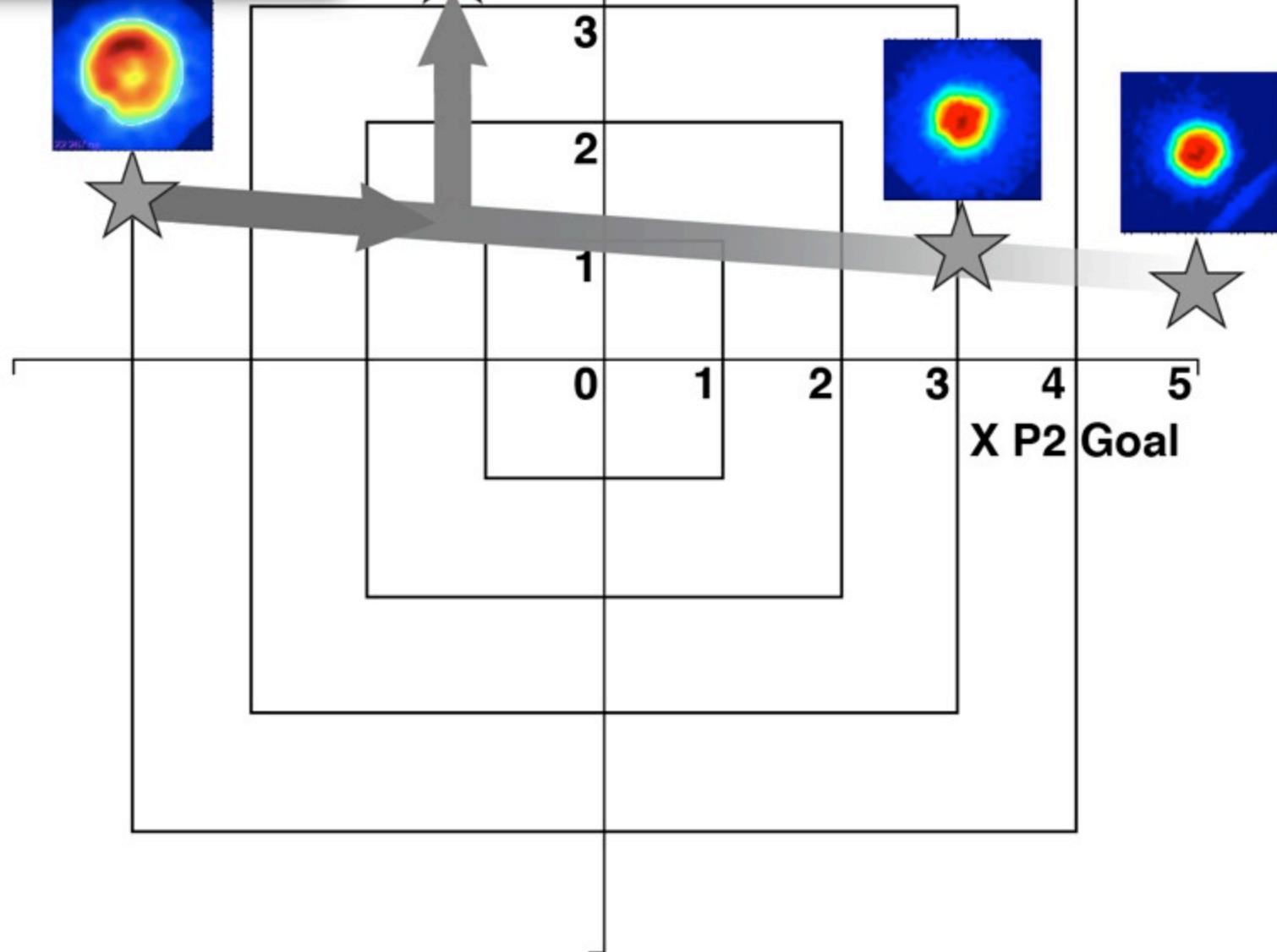
4

5

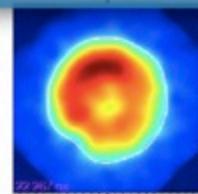
X P2 Goal



-  Symcap
-  THD/DT



Shot 5
M4 sensitivity to
“3-color or λ_3 ”



5 X M4 Goal

★ Symcap
★ THD/DT

4

3

2

1

0

1

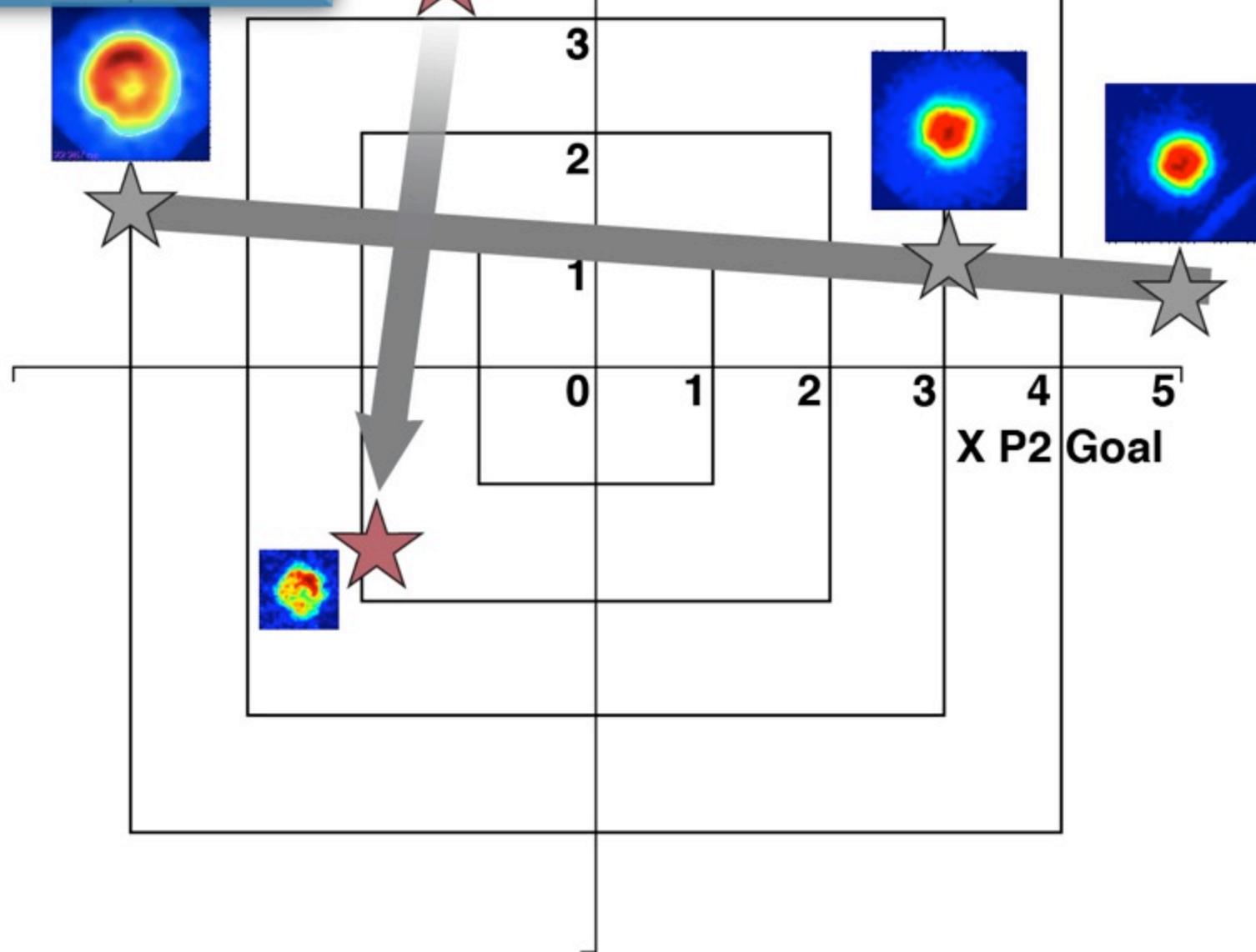
2

3

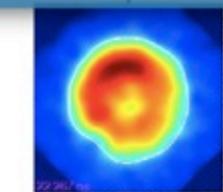
4

5

X P2 Goal



Shot 6
**Symcap-DT shape
surrogacy check**



5 X M4 Goal

4

3

2

1

0

1

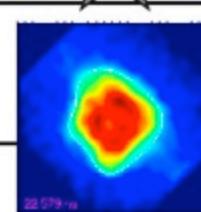
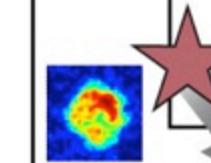
2

3

4

5

X P2 Goal

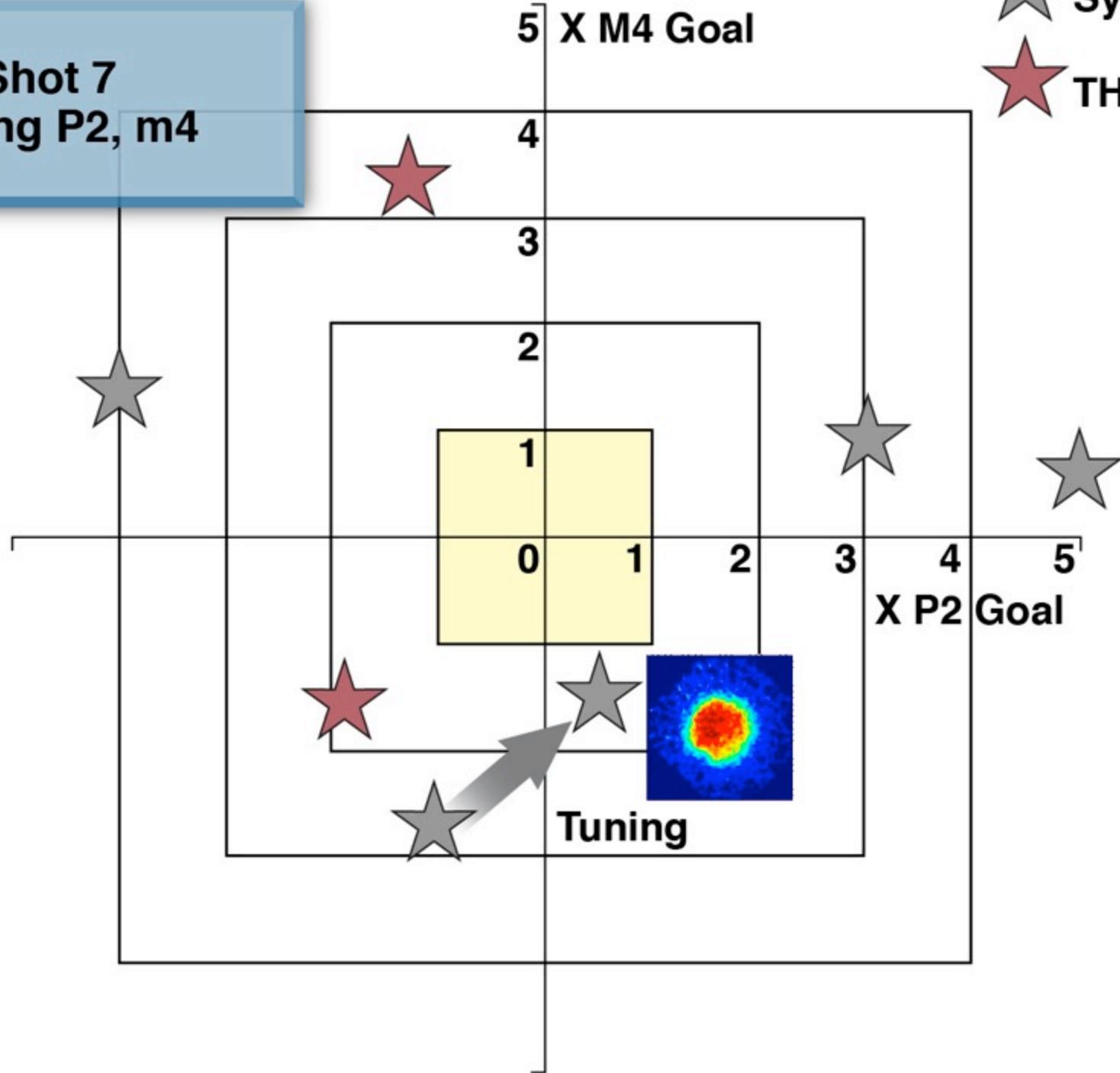


- ★ Symcap
- ★ THD/DT

Shot 7
Tuning P2, m4

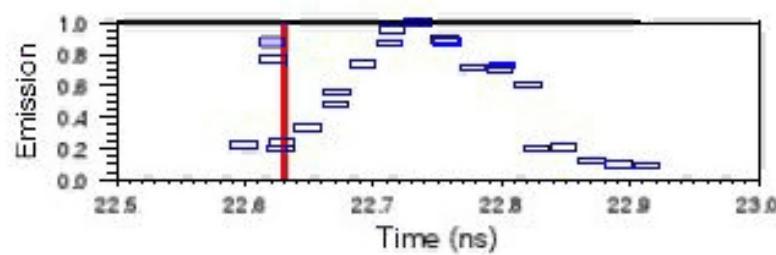
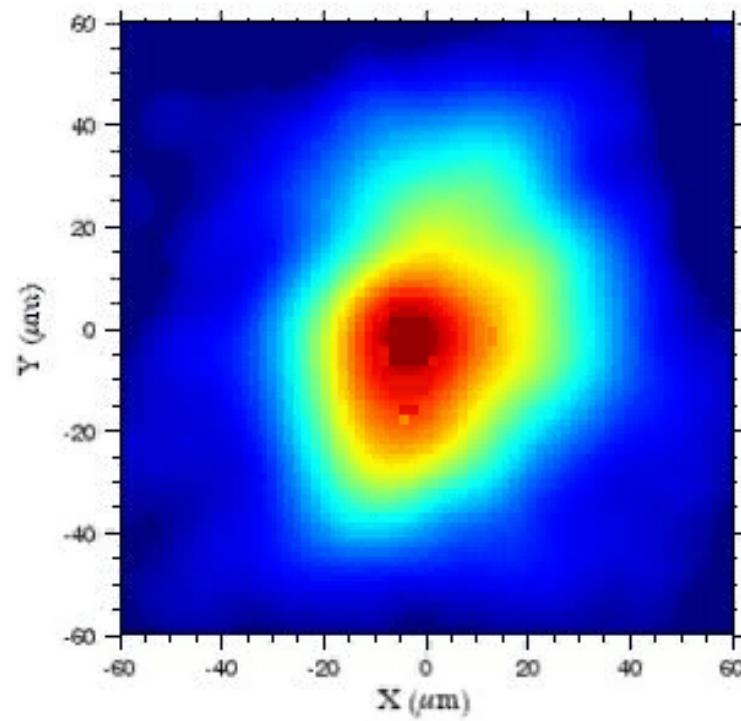
5 X M4 Goal

 **Symcap**
 **THD/DT**

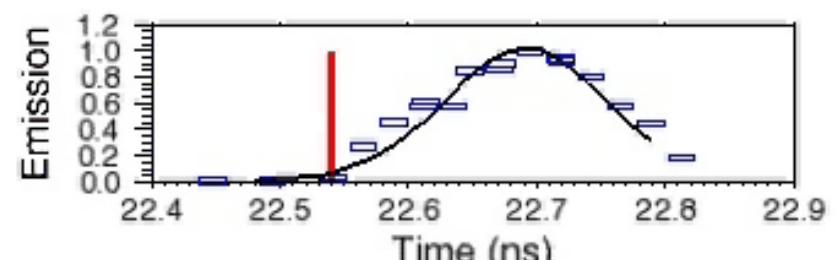
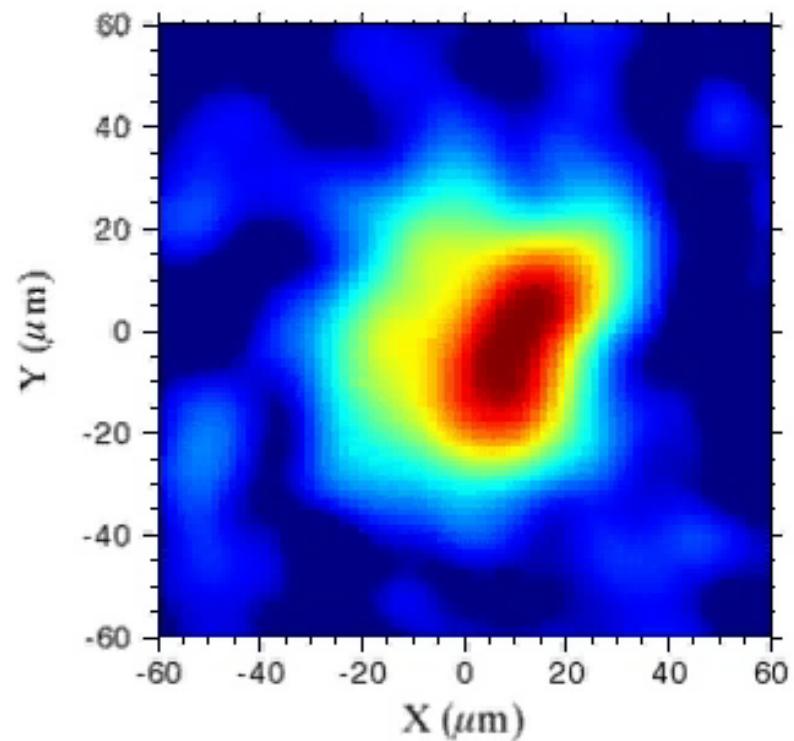


Most recent DT implosion experiments show efficient compression and a symmetric hot spot

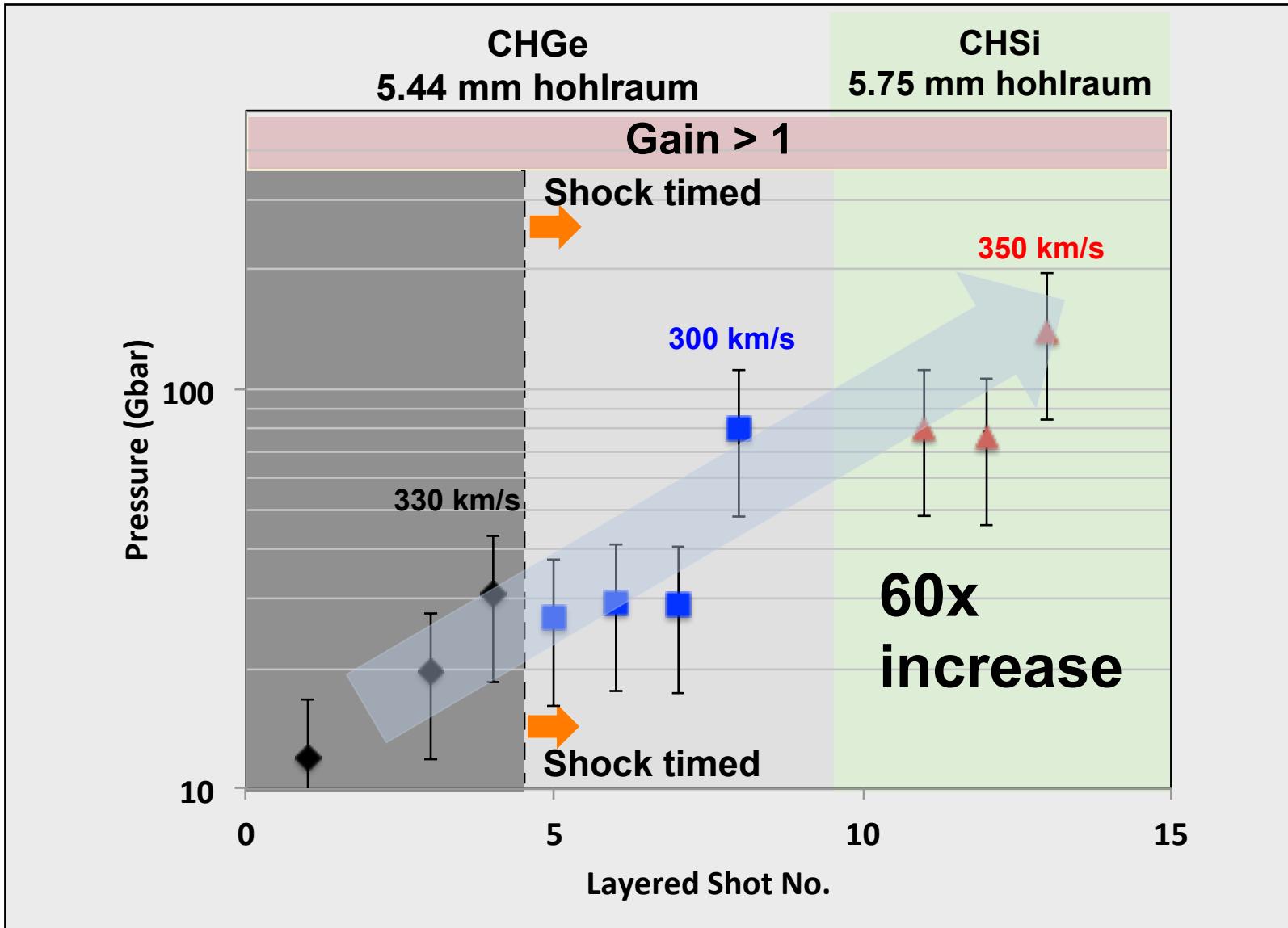
9 keV x-ray emission in the equatorial direction N120205



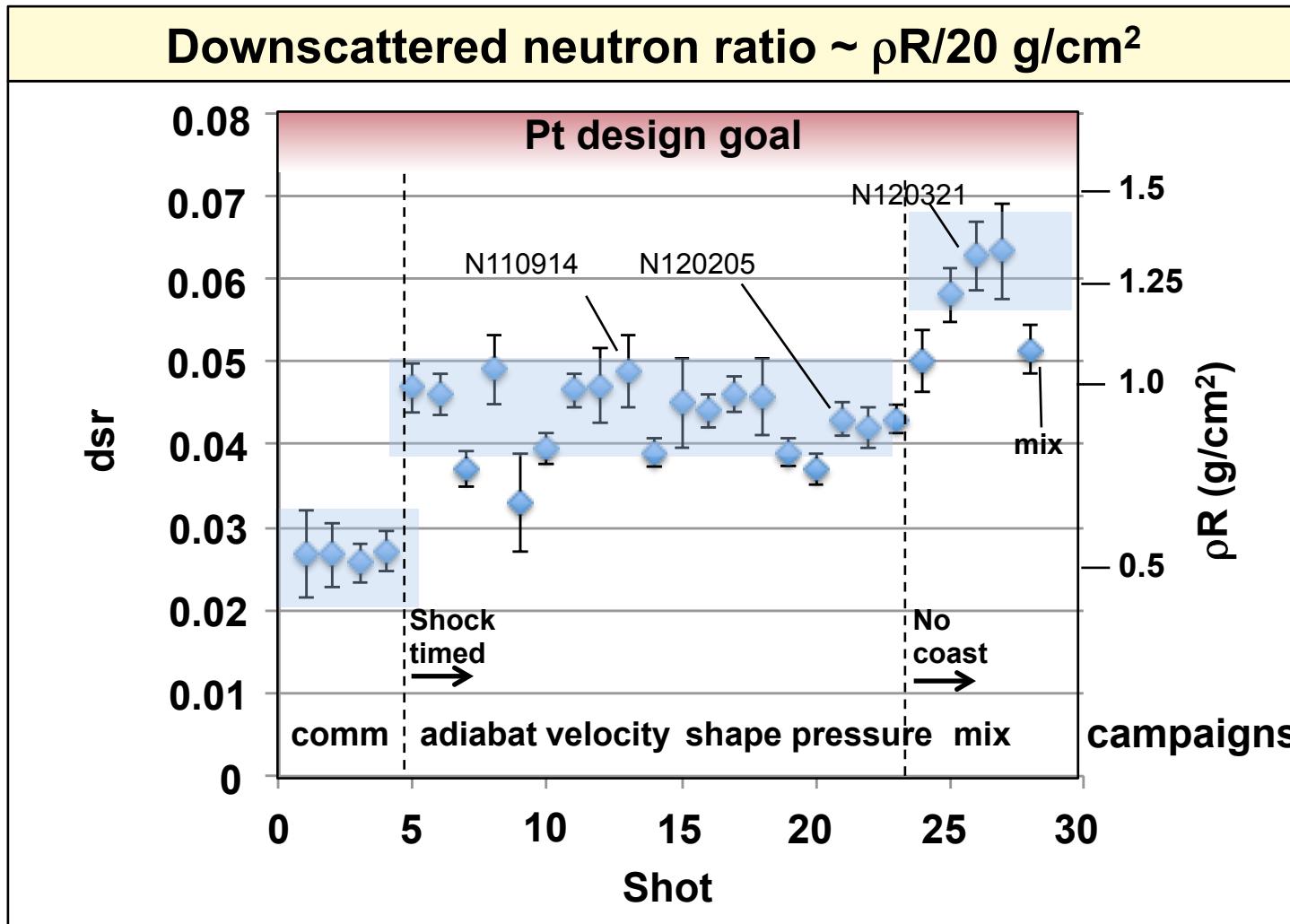
9 keV x-ray emission in the polar direction N120205



Pressures are judged to be within ~3X of ignition regime



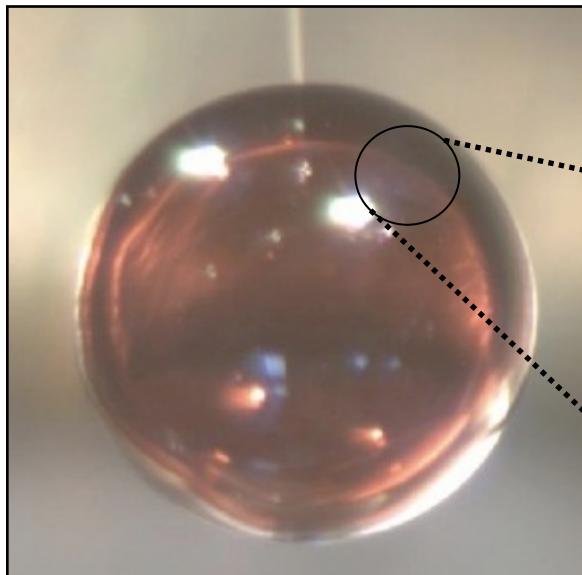
Recent experiments have increased DT fuel areal density to $\rho R > 1.2 \text{ g/cm}^2$ at stagnation



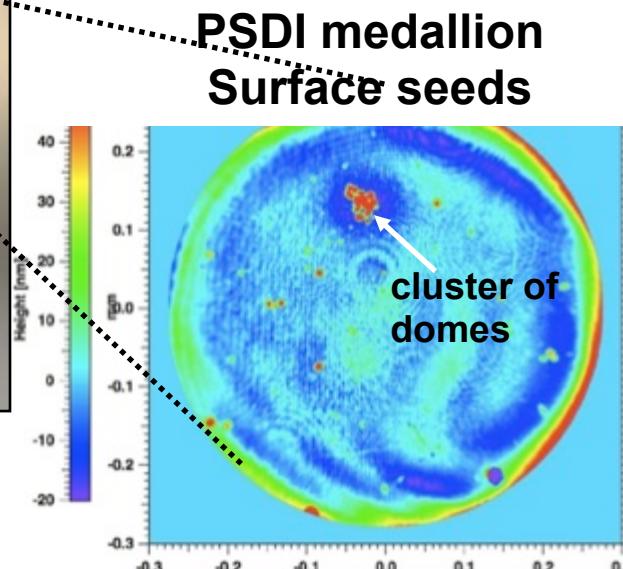
Recent improvement attributed to reduction in coasting (longer laser pulse)

Mix is the focus of the next few months

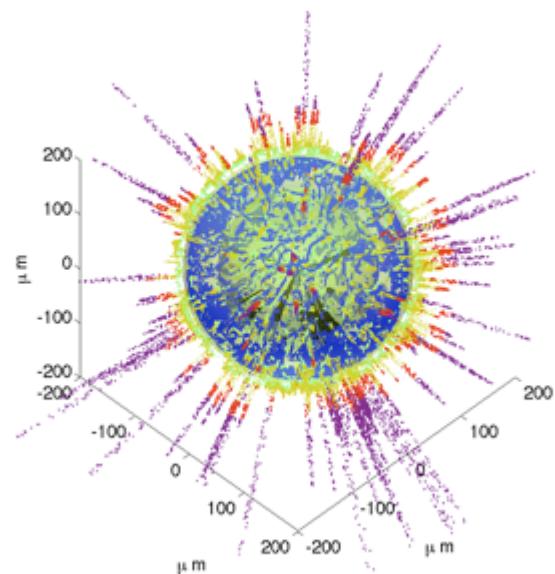
CH capsule



↔ ~ 2 mm

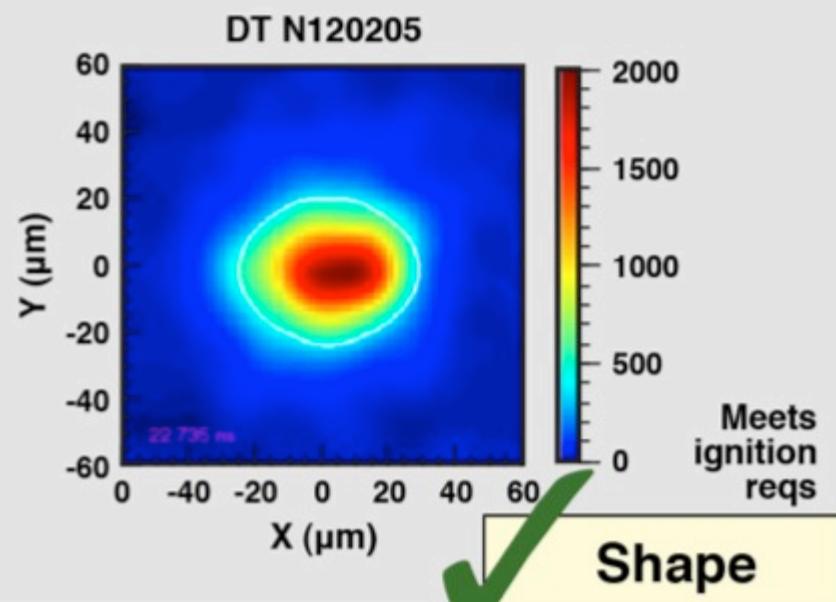
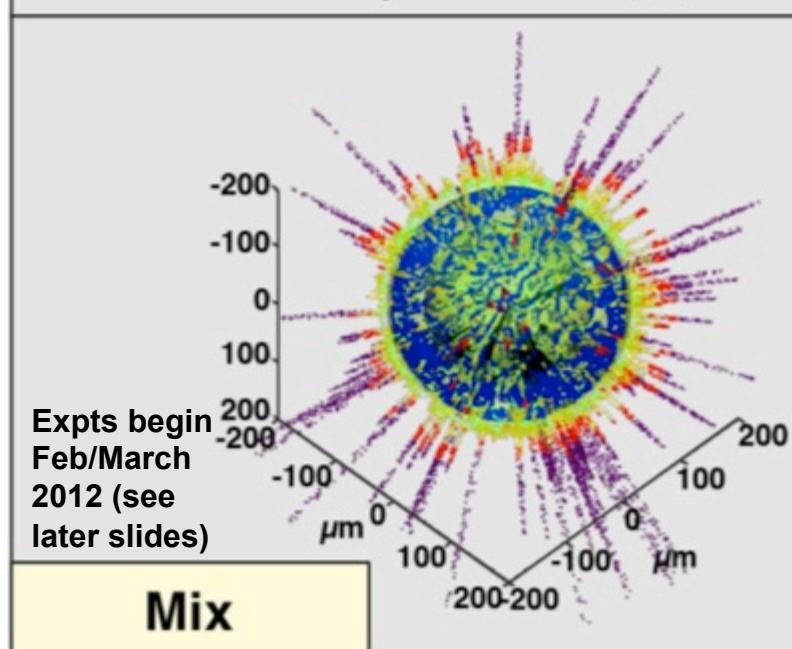
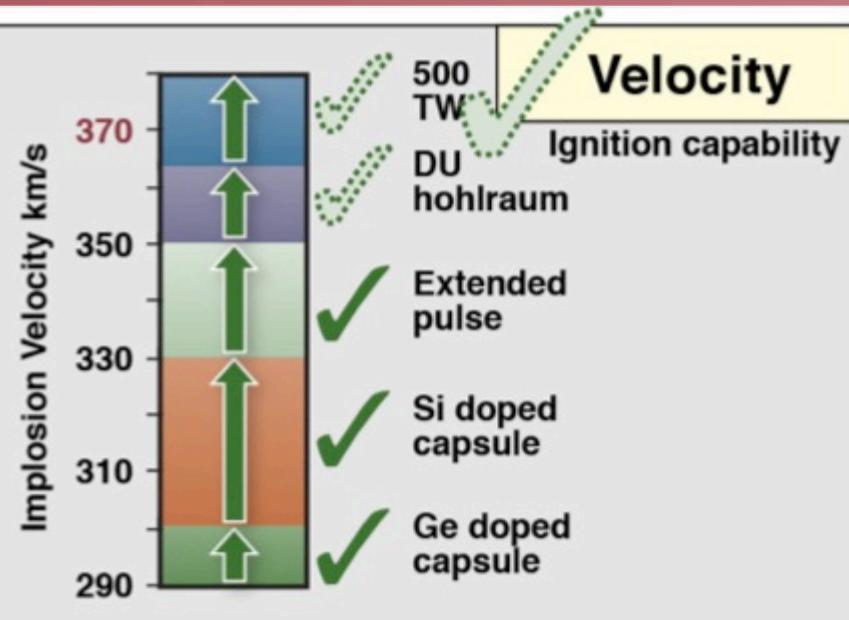
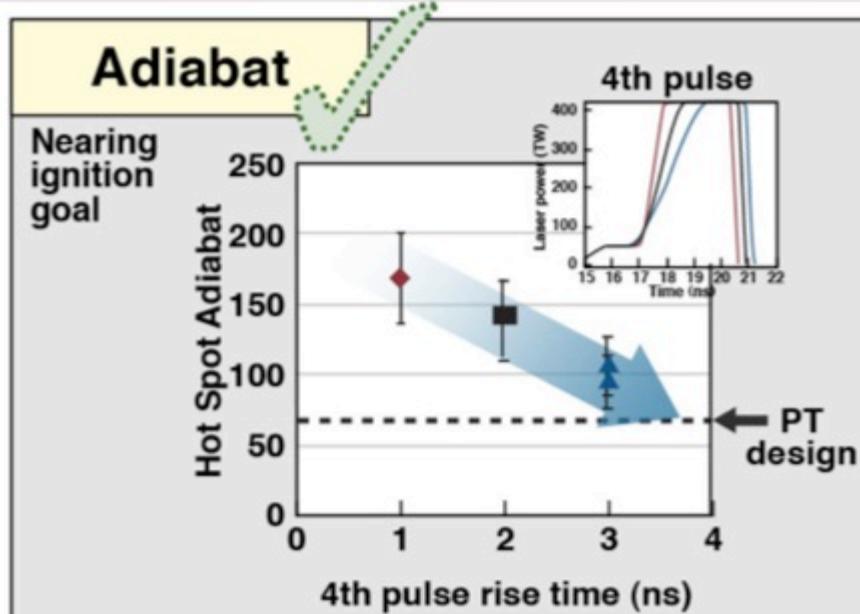


Seeds grow during
implosion

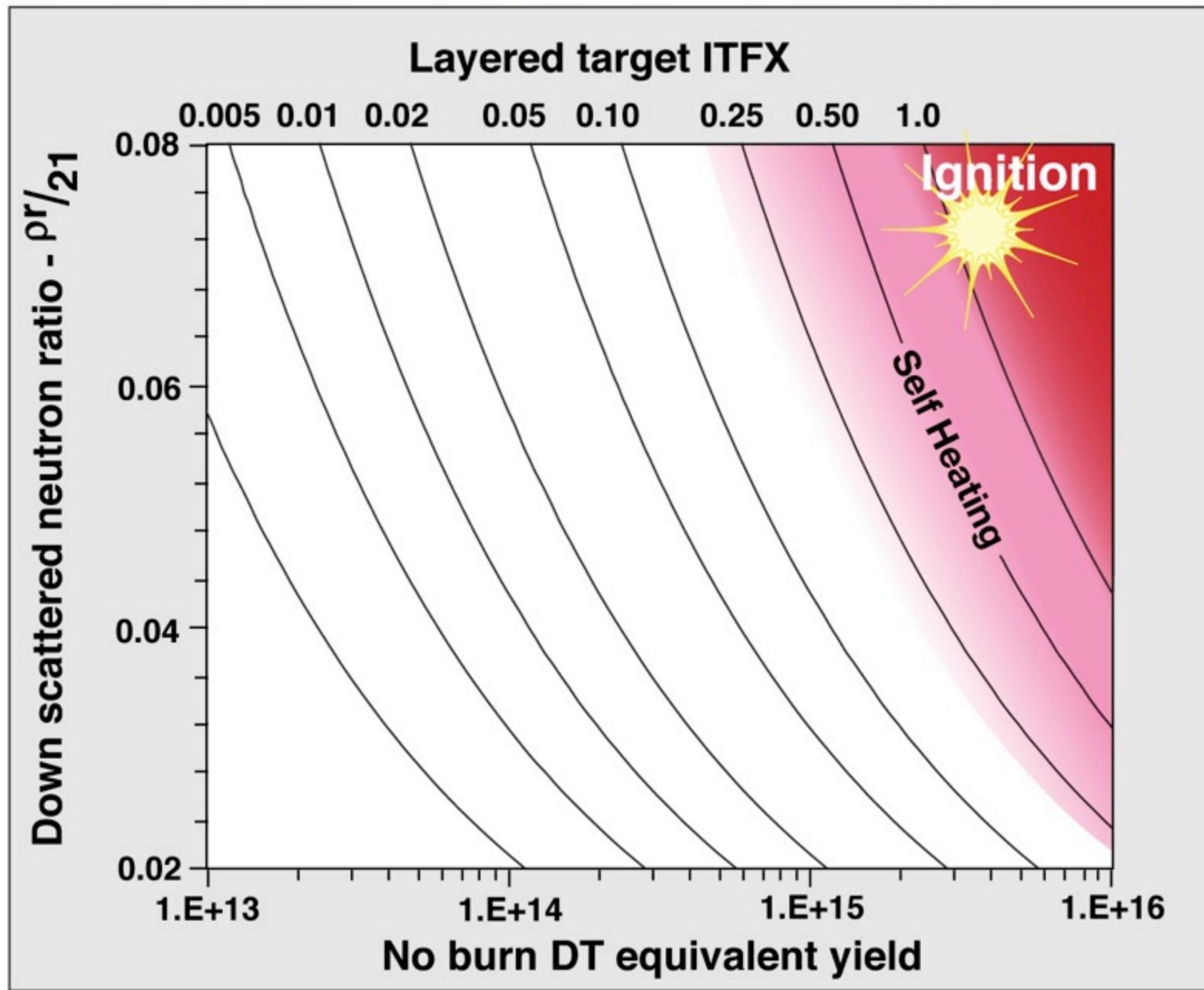


Too much mix causes shell break up and loss of performance

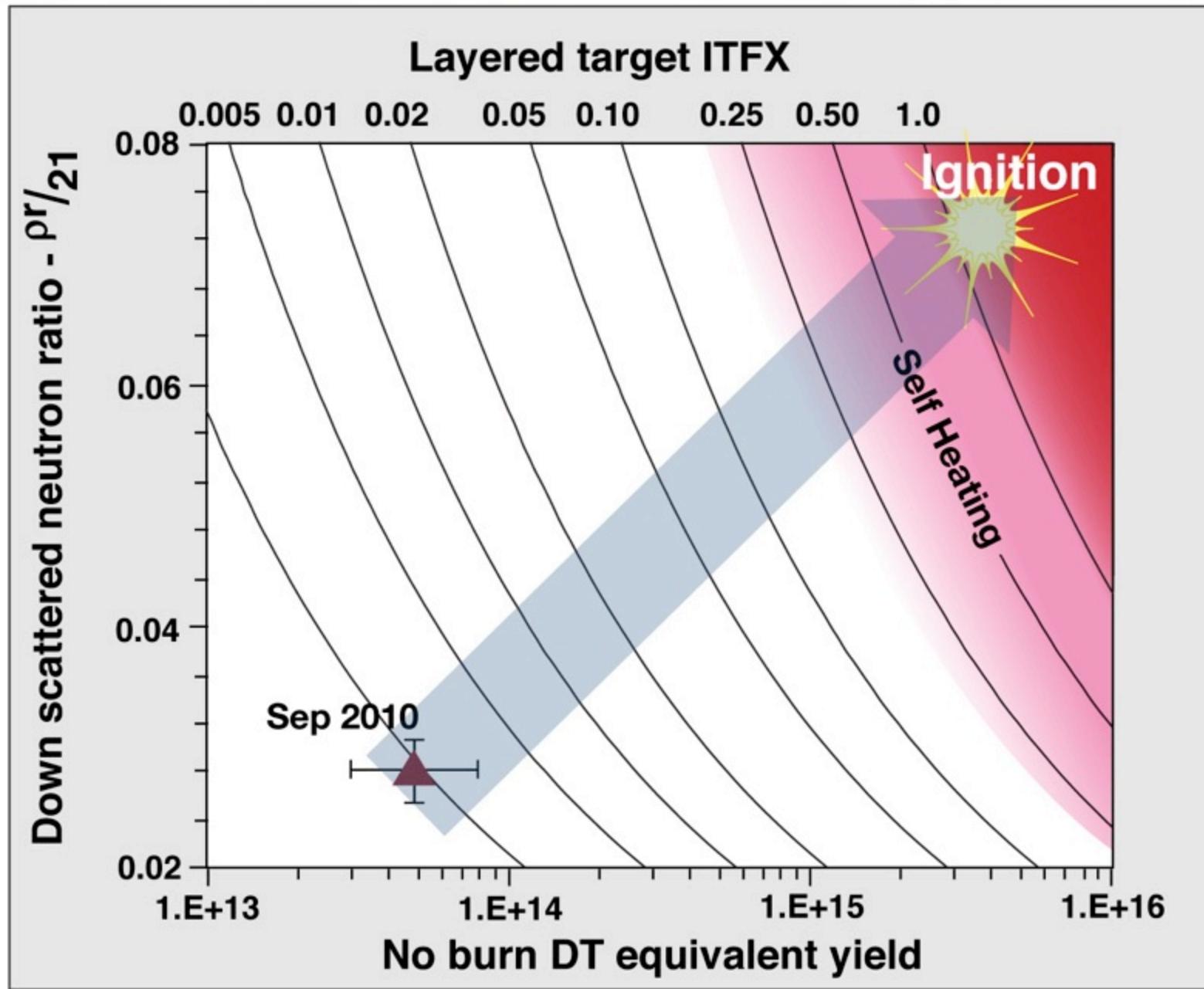
Progress on implosion parameters



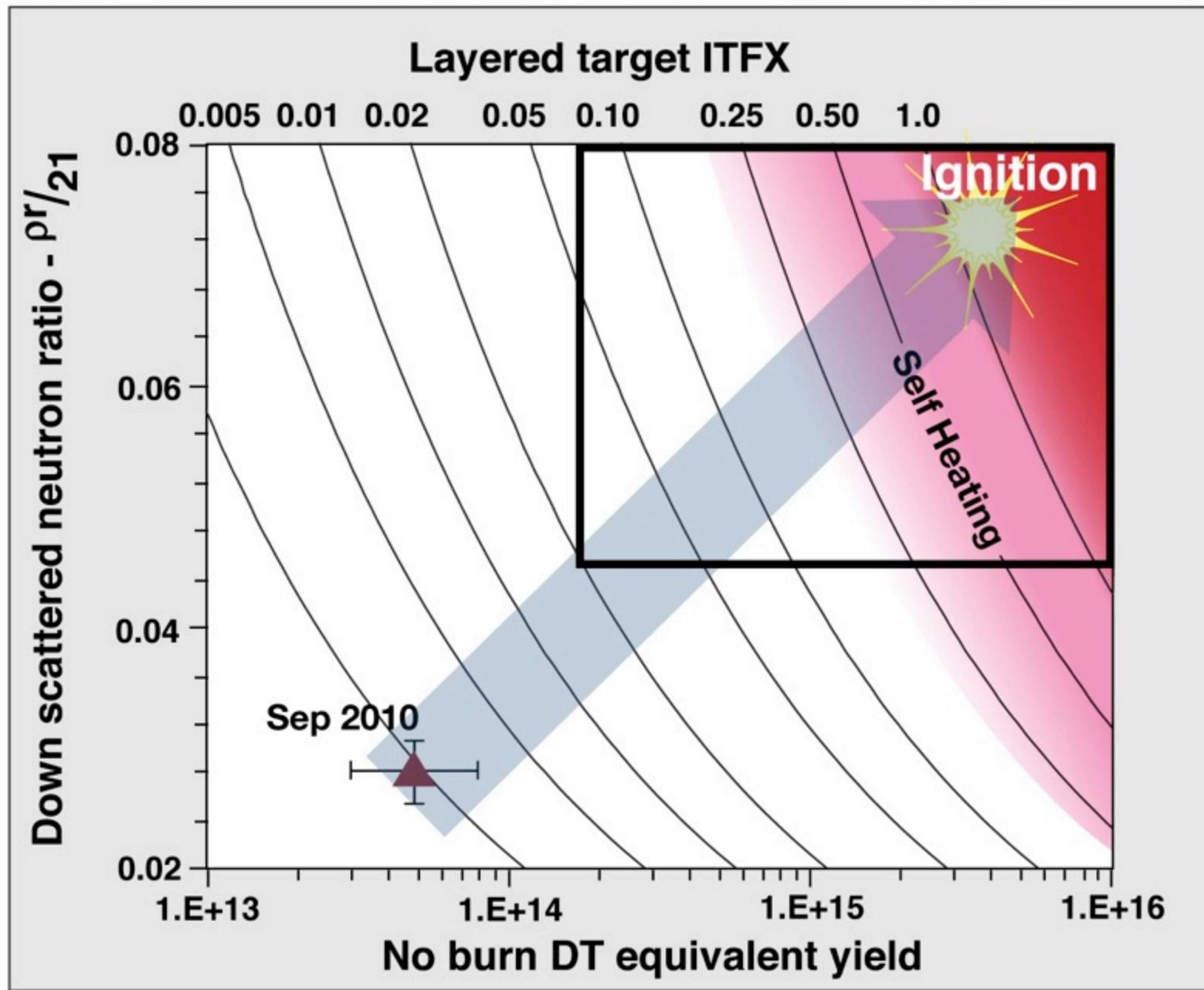
Pathway to Ignition



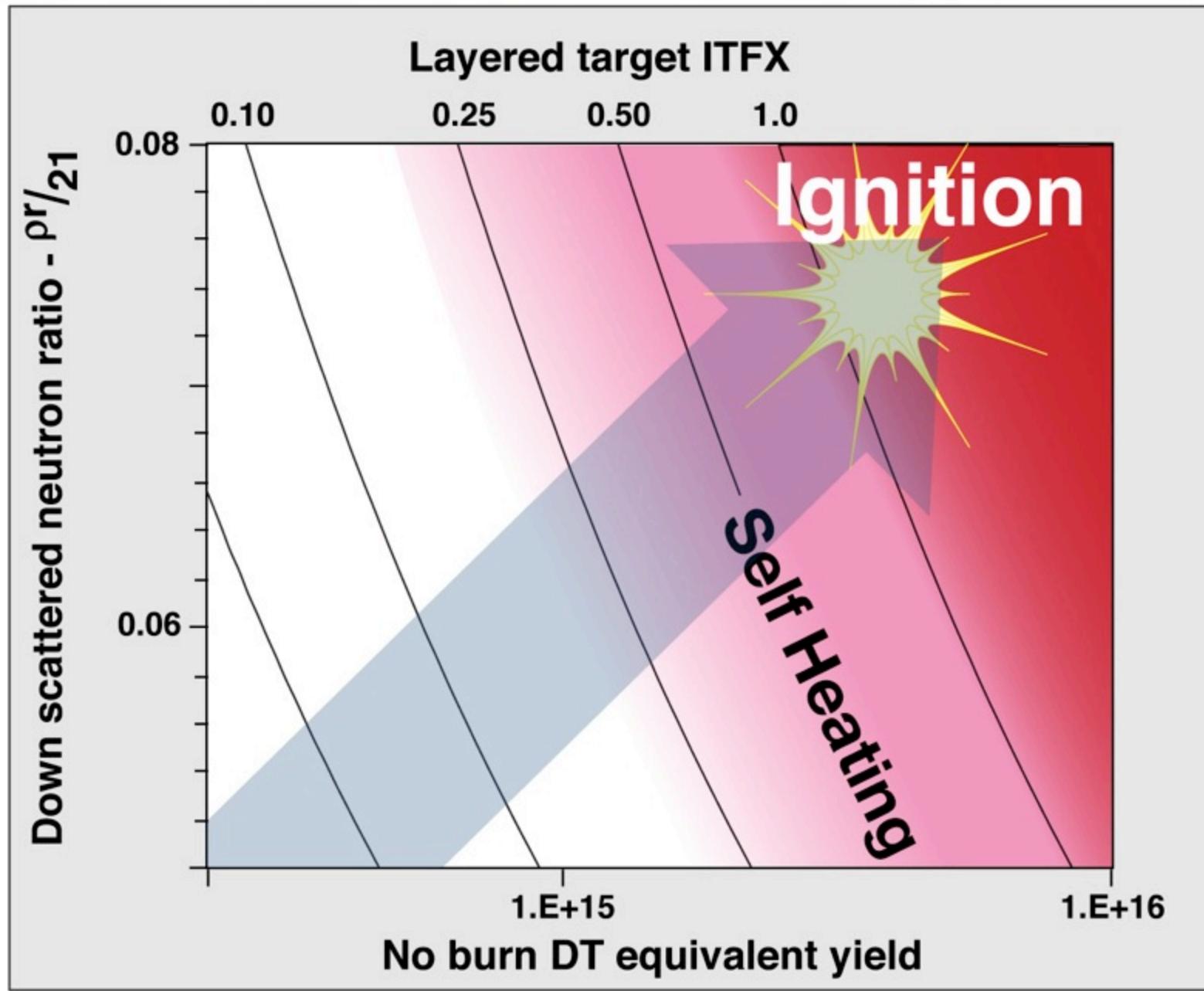
Pathway to Ignition



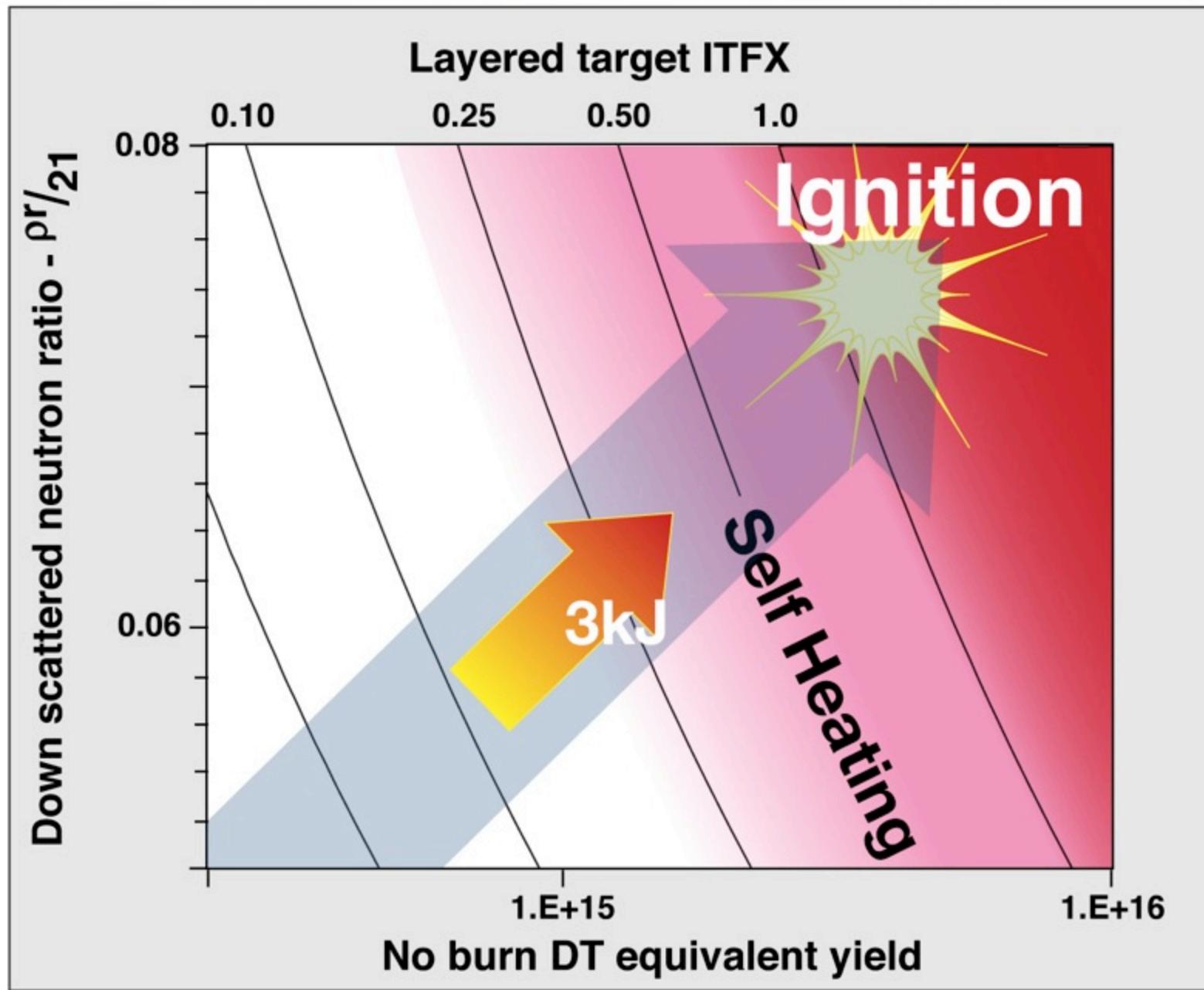
Pathway to Ignition



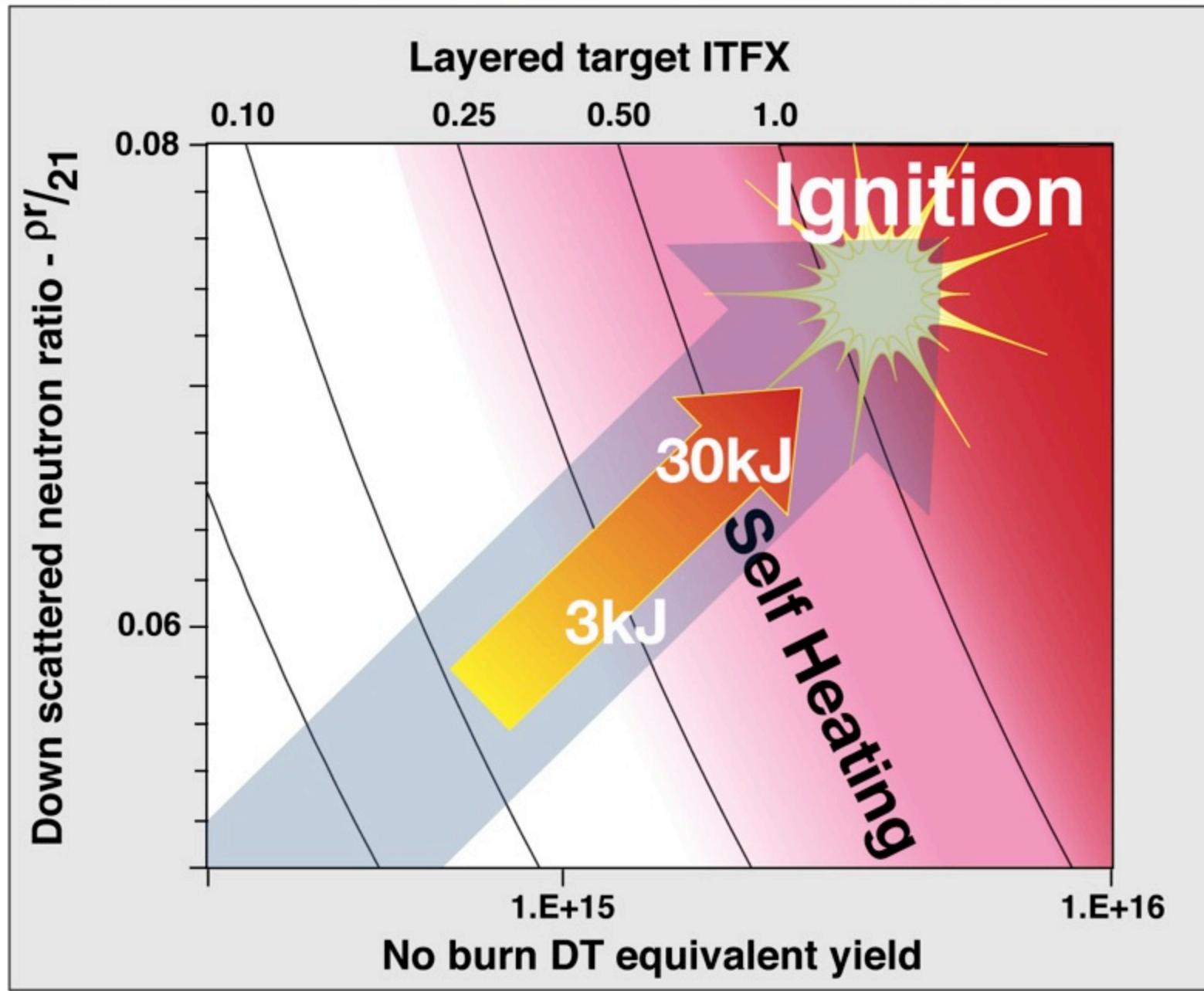
Pathway to Ignition



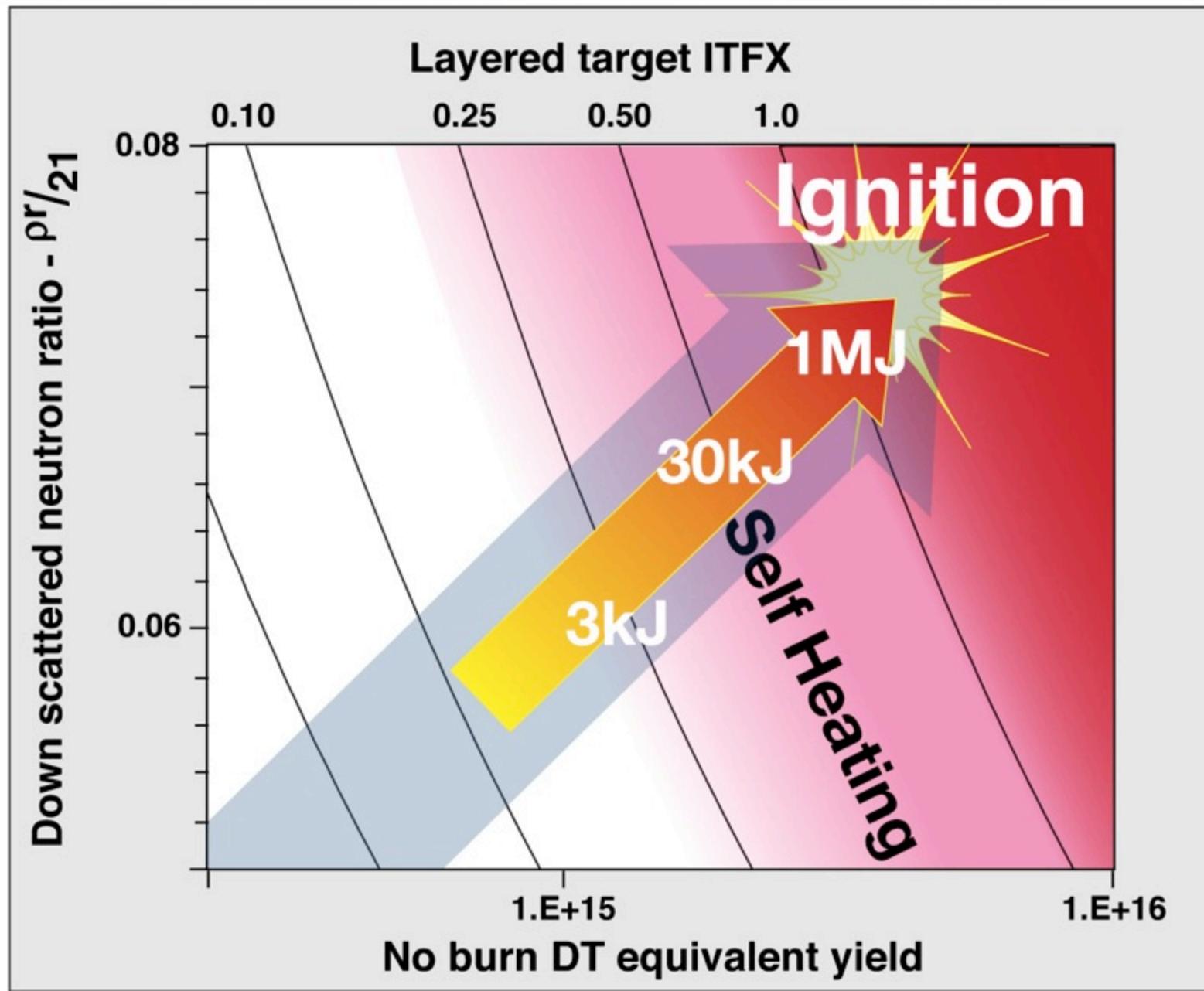
Pathway to Ignition



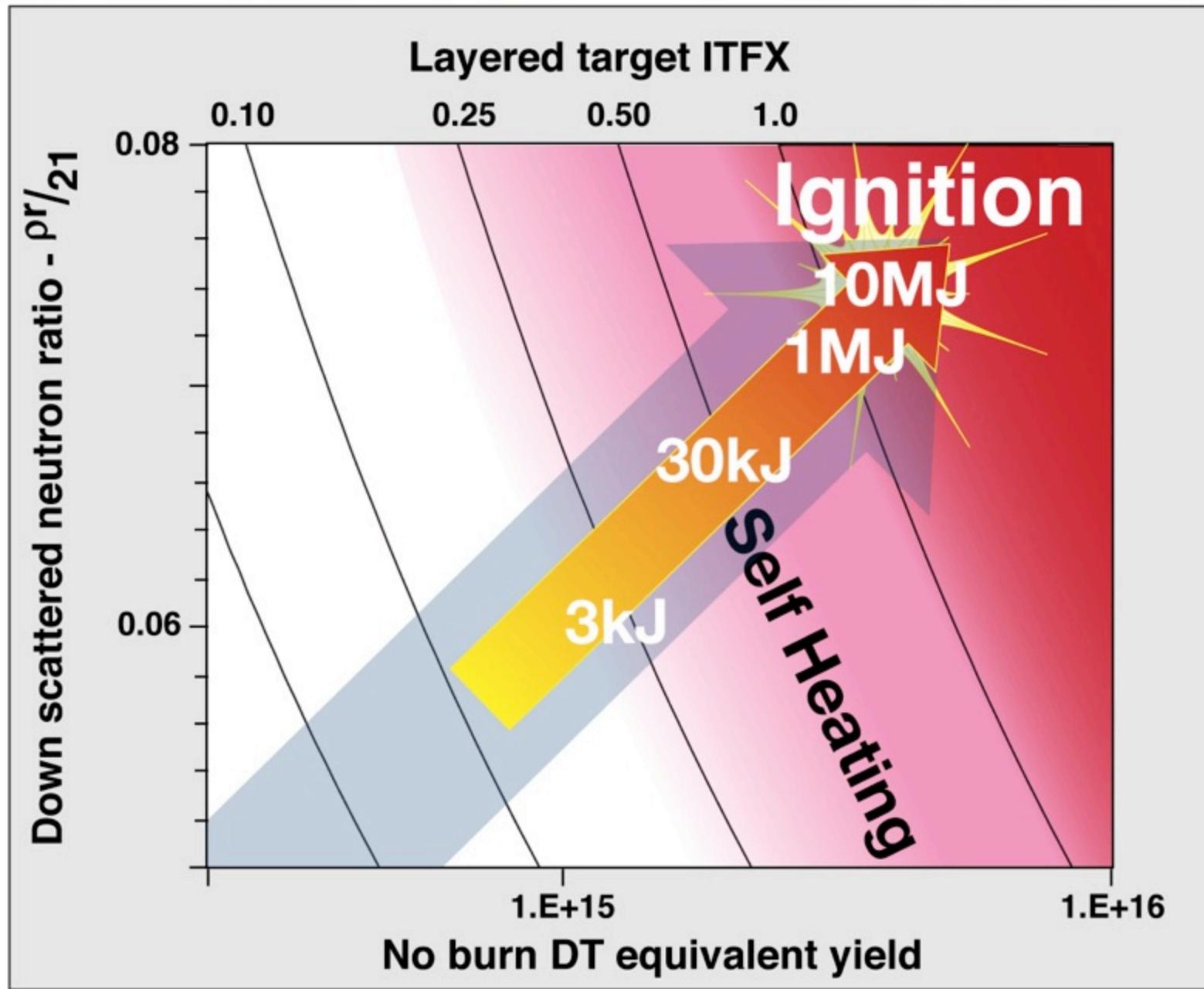
Pathway to Ignition



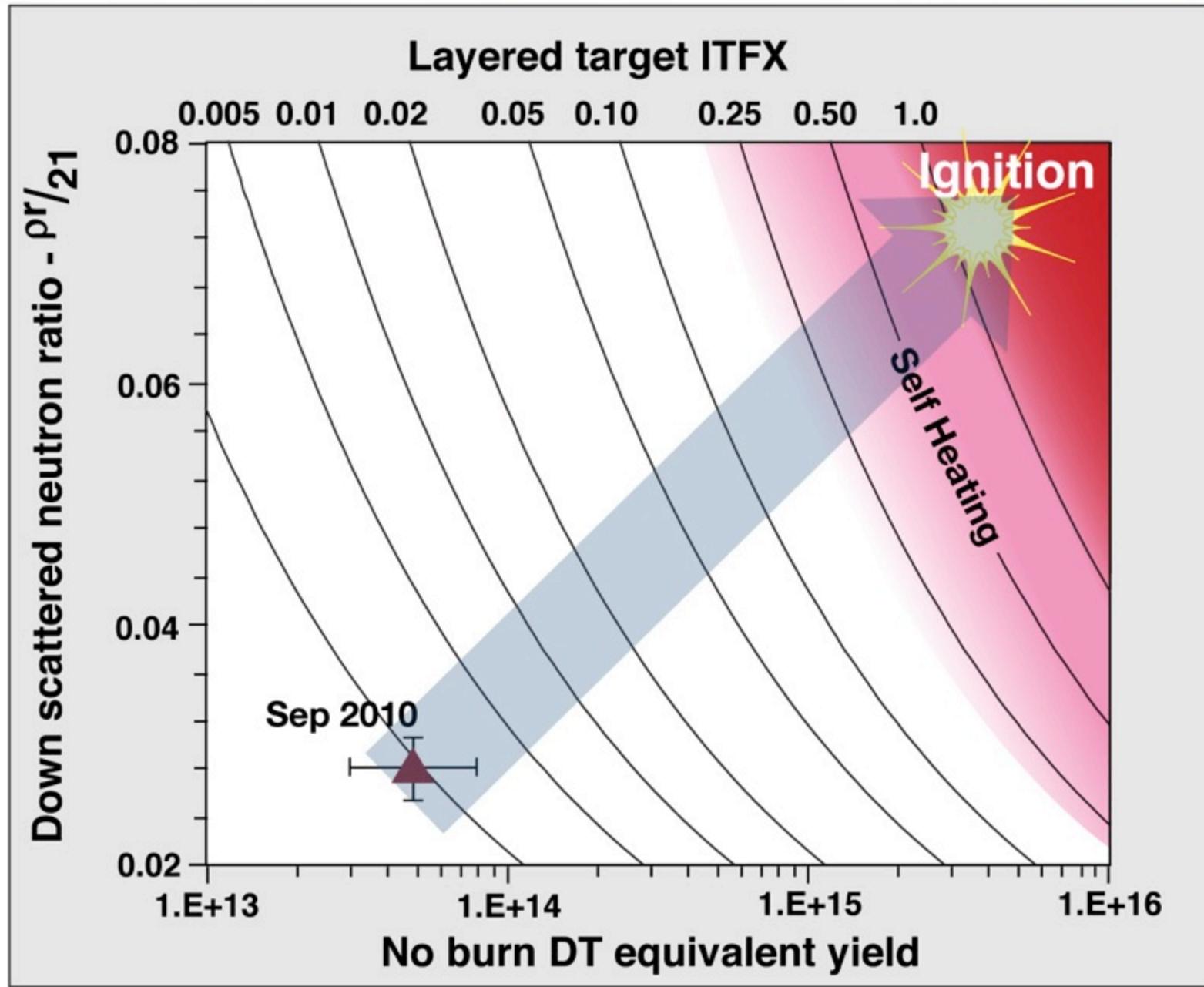
Pathway to Ignition



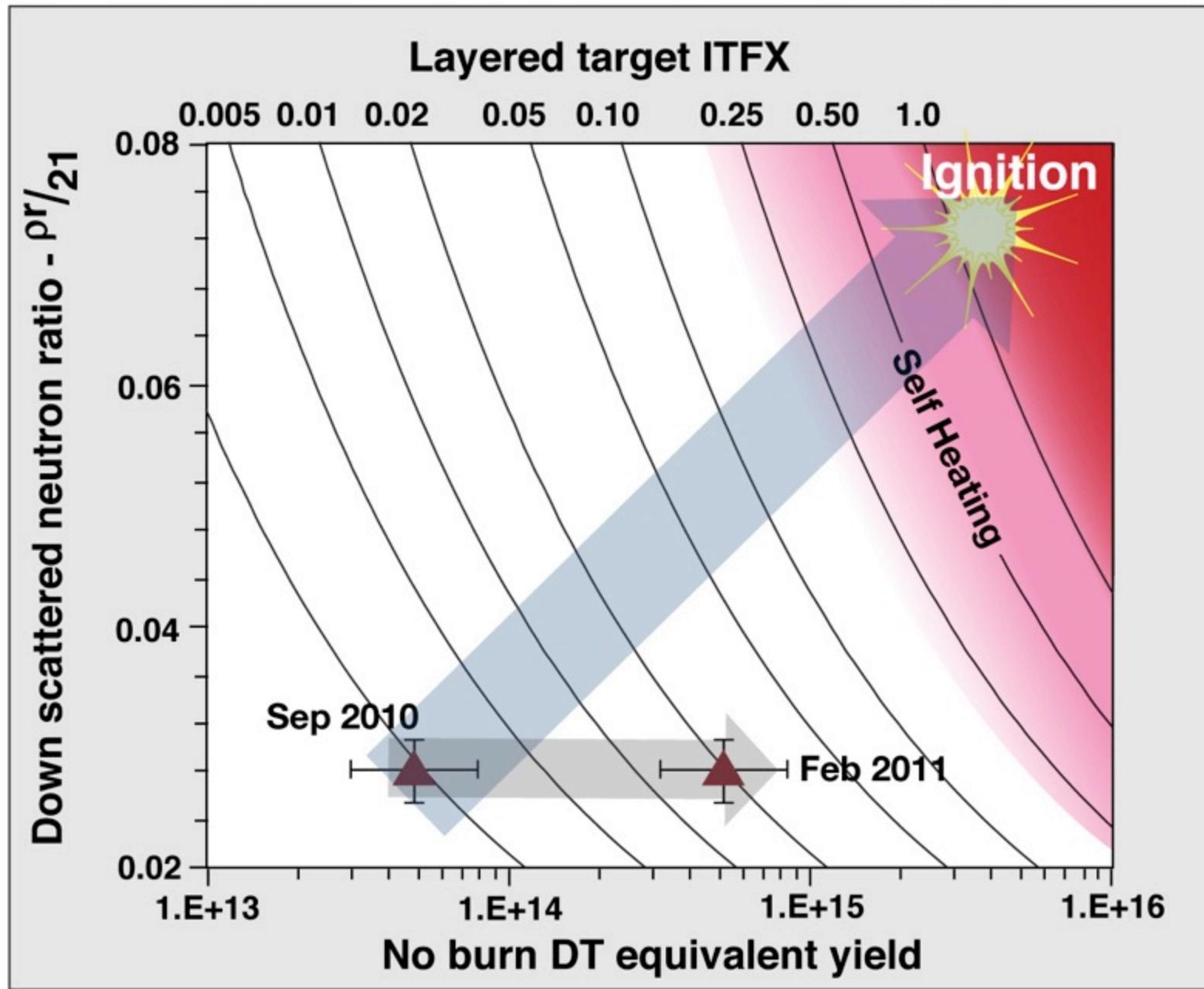
Pathway to Ignition



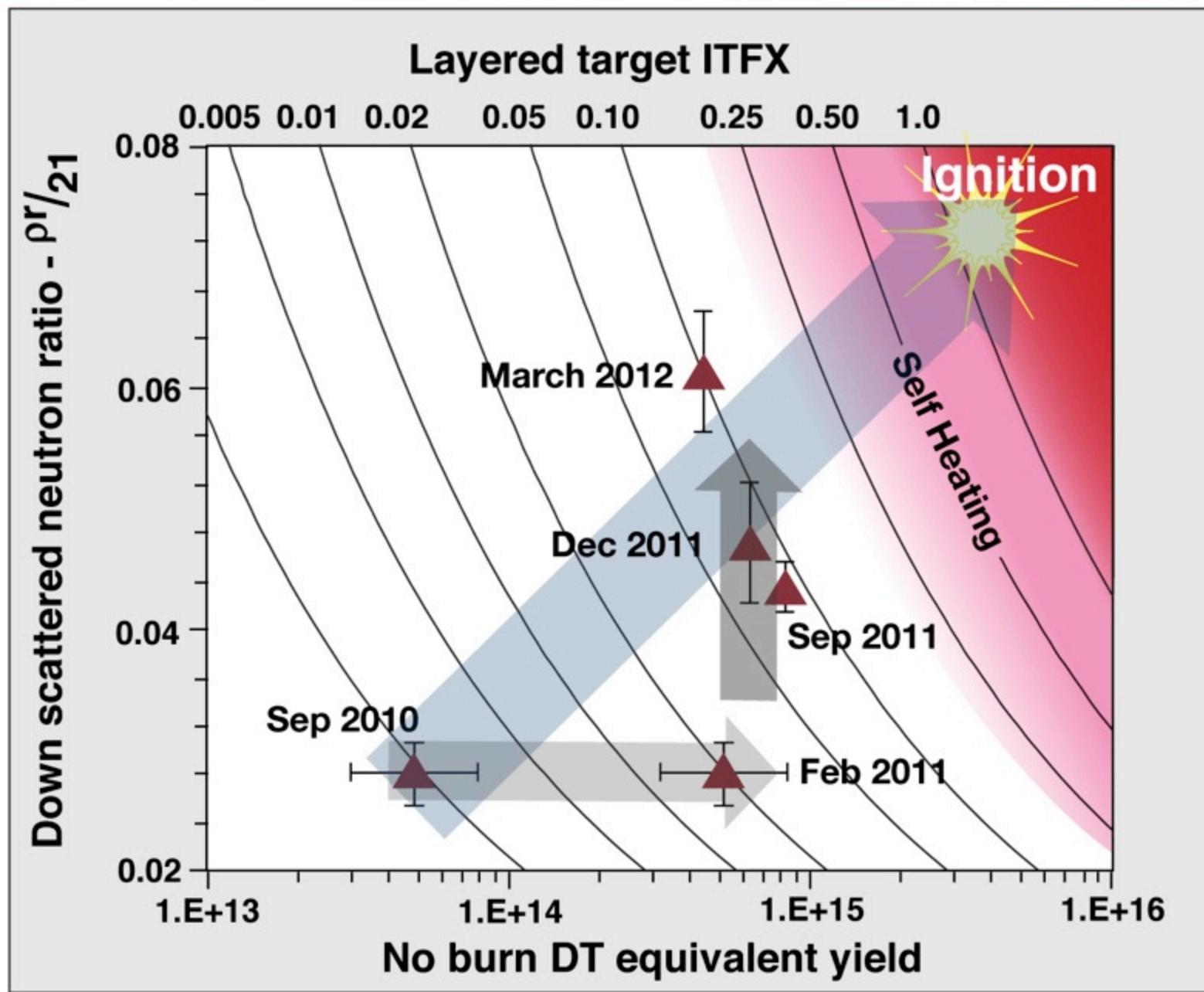
Pathway to Ignition



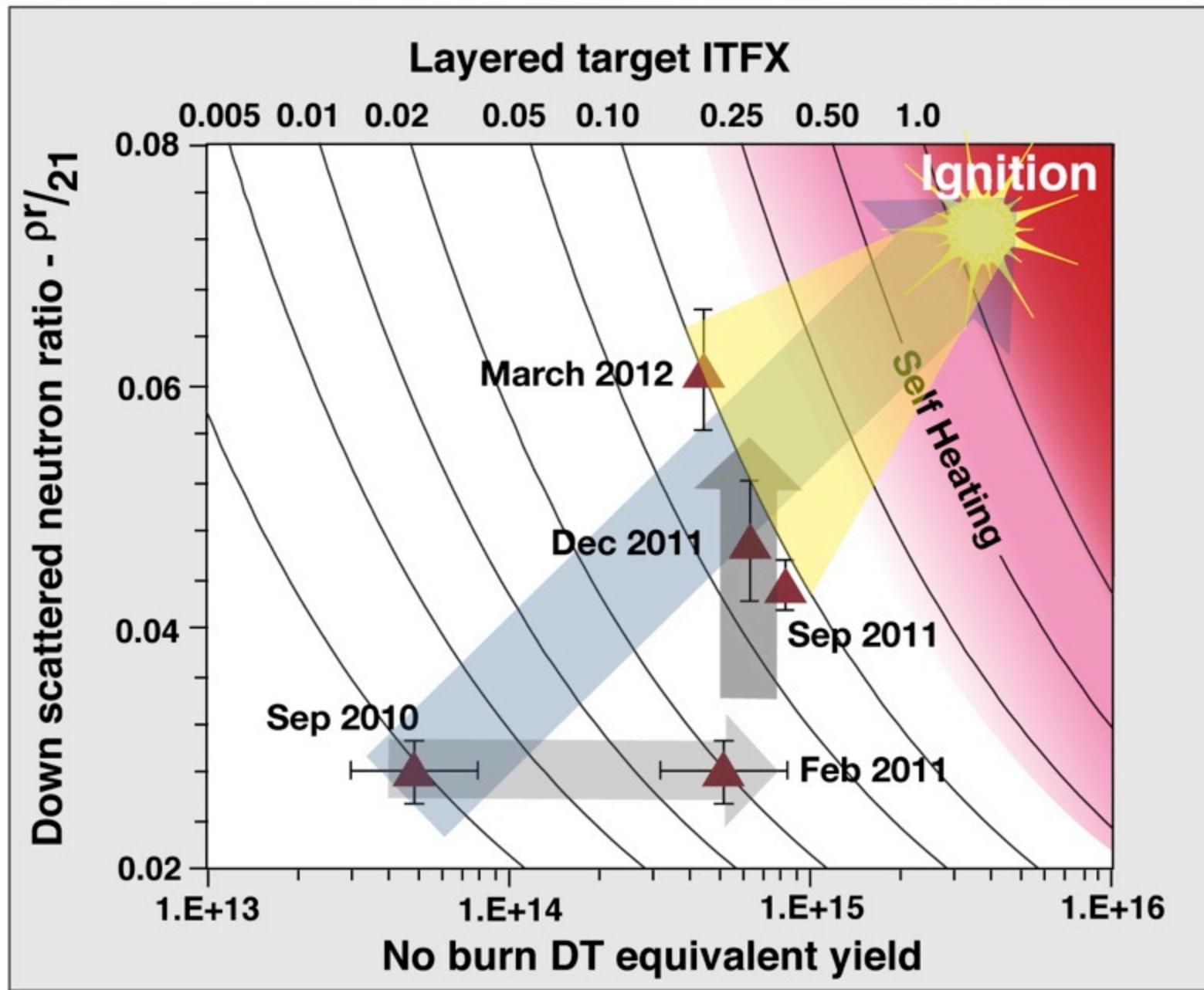
Pathway to Ignition



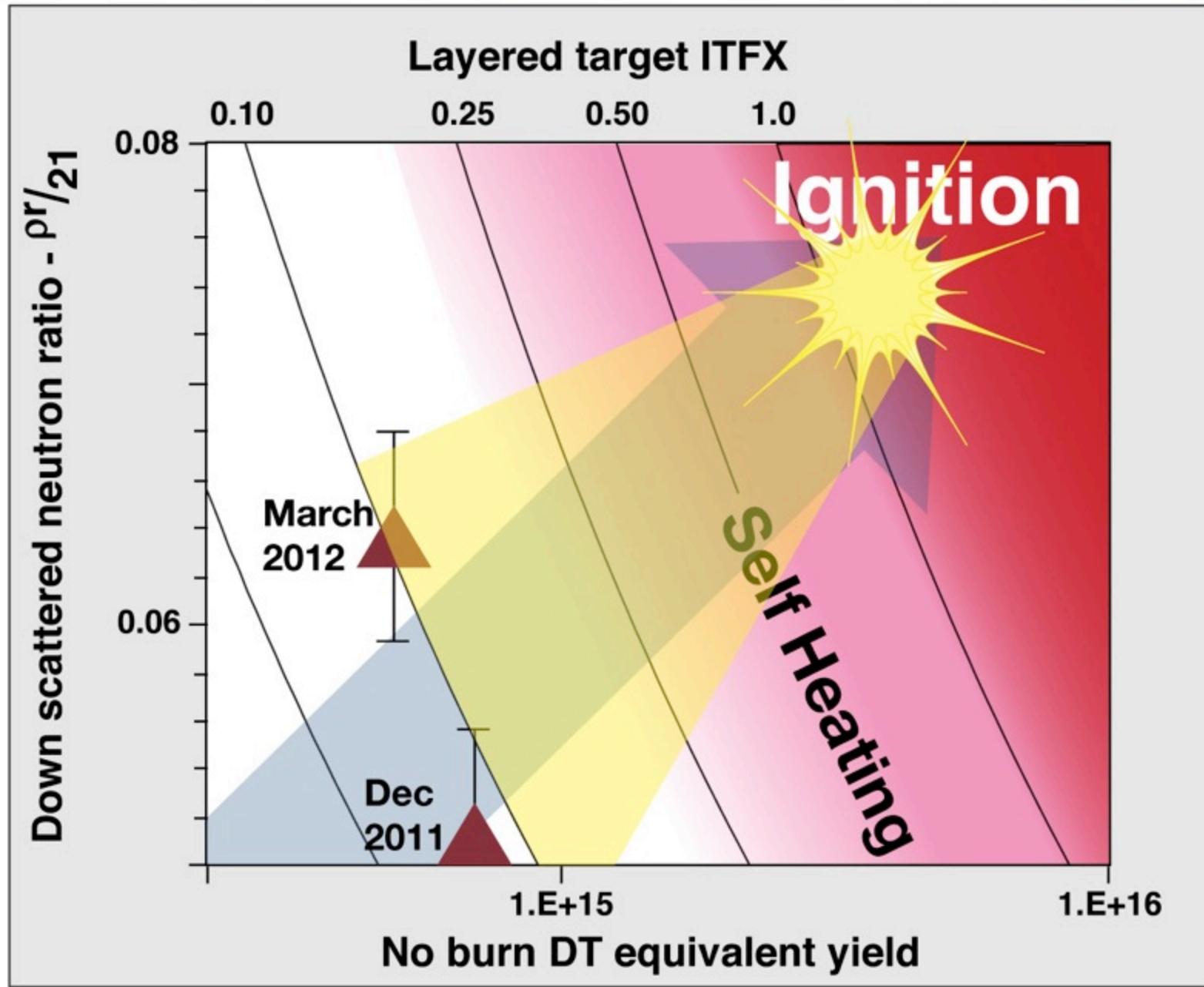
Pathway to Ignition



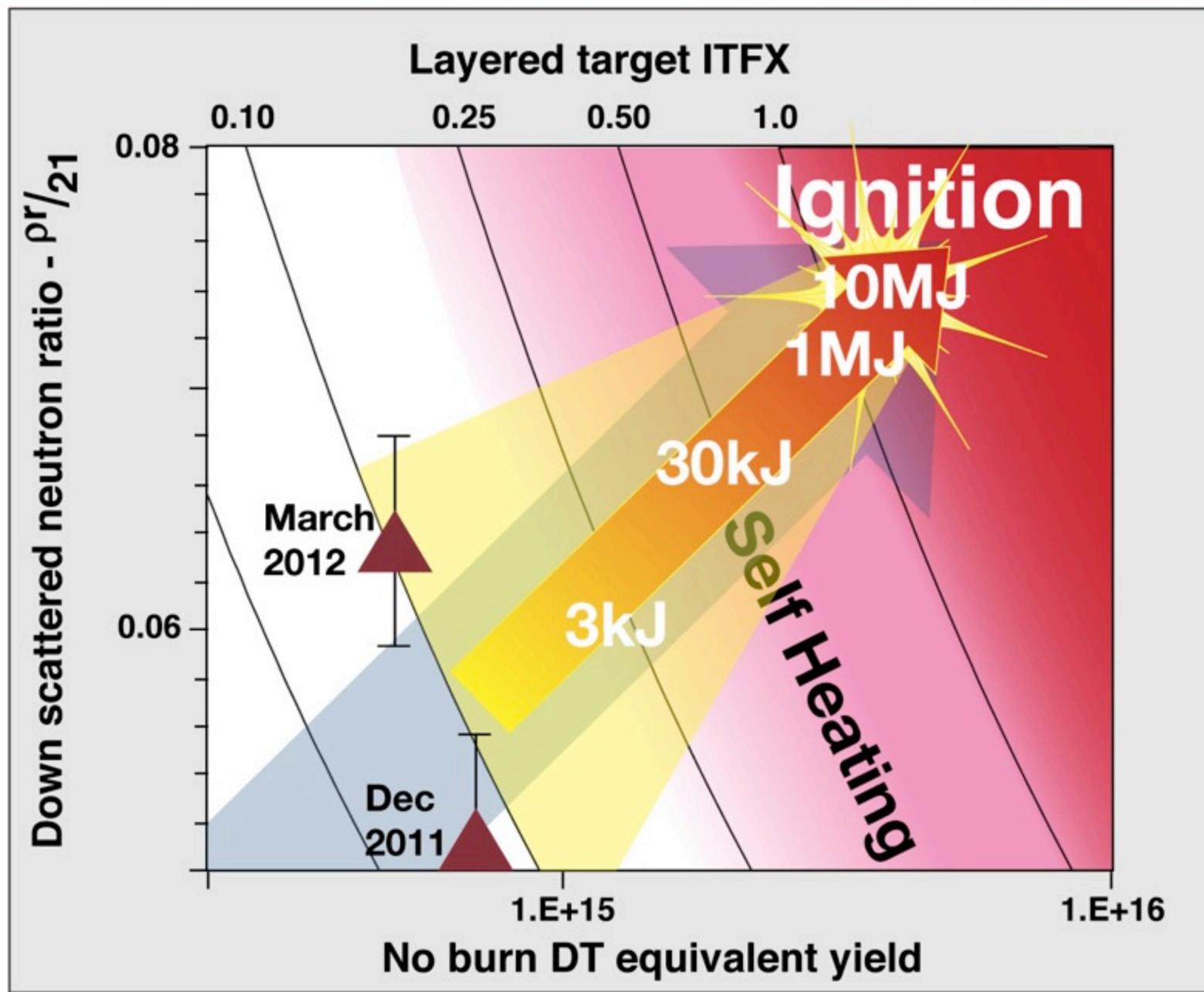
Pathway to Ignition



Pathway to Ignition



Pathway to Ignition



Summary status of the National Ignition Campaign

- NIF laser operating 24/7 with exceptional reproducibility & reliability
- NIF achieved sustainable operations at its design point (1.8 MJ / 500 TW)
- NIF optics quality and laser performance consistent with performance significantly greater than the design spec (1.8MJ)
- Hohlraum energetics campaign started in August 2009
 - Laser-plasma instability losses are acceptable
 - Laser-plasma coupling has provided a robust tuning mechanism
 - Required hohlraum temperature achieved
- Cryogenic layered implosion campaign started in September 2010
- Precision optimization started in May 2011
 - Implosion velocity: path to exceeding required value
 - Implosion shape: controllability of low-order m- and l- modes
 - Shock timing (adiabat): issues with 4th shock pressure
 - Mix: current campaign focus
- Pathway to ignition continues to follow the established NIC methodology
- Plans for progress beyond 2012 will be reported to Congress in November

Thanks to the NIF team

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NIC

